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INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board to reorganize the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

Section 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

Section 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

Section 3.—*Forecasts and general conditions of the atmosphere.*

Section 4.—*Rivers and floods.*

Section 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

Section 6.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that, during recent years, have been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in Section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the Review as a whole can only issue from the press within about eight weeks from the end of that month.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due to the following directors and superintendents:

The Meteorological Service of the Dominion of Canada.

The Central Meteorological and Magnetic Observatory of Mexico.

The Director General of Mexican Telegraphs.

The Meteorological Service of Cuba.

The Meteorological Observatory of Belen College, Habana.

The Government Meteorological Office of Jamaica.

The Meteorological Service of the Azores.

The Meteorological Office, London.

The Danish Meteorological Institute.

The Physical Central Observatory, St. Petersburg.

The Philippine Weather Bureau.

The General Superintendent United States Life-Saving Service.

SECTION I.—AEROLOGY.

SOLAR RADIATION INTENSITIES AT MOUNT WEATHER, VA., DURING APRIL, MAY, AND JUNE, 1914.

By HERBERT H. KIMBALL, Professor of Meteorology.

[Dated Mount Weather, Va., July 16, 1914.]

In Table 1 are summarized the solar radiation measurements made at Mount Weather, Va., with a Marvin pyrheliometer, during April, May, and June, 1914. Measurements have been made with the sun at approximately the following zenith distances, whenever it was unobscured by clouds: 80.7°, 79.8°, 78.7°, 77.4°, 75.7°, 73.6°, 70.7°, 66.5°, 60.0°, and 48.3°, with an additional observation as near noon as possible, at which time the sun's zenith distance has varied from 33° in April to 18° in June.

For details relative to the standardization of the Marvin pyrheliometer, and the interpolation of readings to the air masses given in the heading of Table 1, see page 138 of the current volume of this REVIEW.

Both the maximum and the mean radiation intensities measured in April and June, 1914, equal those of corresponding months in previous years, and exceed those of 1913, and of June, 1912. From May 19 to May 27, inclusive, the radiation intensity was considerably below the average, probably on account of the smokiness of the atmosphere, due to forest fires in States north and west of Virginia. Through the courtesy of the Chief of Forest Service we are able to quote the following from the manuscript report by K. W. Woodward, Forest Inspector:

> On account of the long-continued dry weather the fire situation is very serious throughout the Southern Appalachians and White Mountains. At the present time large fires are burning near Government land in the White Top, Unaka, and Smoky Mountain areas. Ordinarily there would be no damage from fire in the Southern Appalachians this season of the year, because normally the foliage is completely out by this time. But, in most cases, there has been no rain to speak of since the 1st of May.

TABLE 1.—*Solar radiation intensities at Mount Weather, Va., during April, May, and June, 1914.*

[Gram-calories per minute per square centimeter of normal surface.]

Date.	Air masses.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0.	5.5	6.0
1914. A. M.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Apr. 6	1.41	1.27	1.14	1.02	0.93	0.85	0.80	0.75	0.69	0.65	0.63
10	1.40	1.29	1.17	1.07	0.97	0.86	0.79	0.71	0.66	0.61	0.57
13	1.51	1.32	1.21	1.10	1.01	0.93	0.86	0.80	0.75	0.70	0.67
17	1.14	1.04	0.94	......	......	......	......	......	......	......	......
18	1.24	1.14	......	......	......	......	......	......	......	......	......
21	1.47	......	......	......	......	......	......	......	......	......	......
22	......	1.33	1.22	......	......	0.92	0.86	0.80	0.75	0.69	......
30	......	......	0.93	0.84	0.74	0.62	0.53	0.49	0.41	......	......
Means	1.36	1.23	1.10	1.01	0.91	0.84	0.77	0.71	0.65	0.66	0.62
P. M.											
Apr. 9	......	1.29	......	......	......	......	......	......	......	......	......
10	......	1.26	1.12	......	......	......	......	......	......	......	......
11	......	1.04	......	......	......	......	......	......	......	......	......
12	......	1.27	1.12	1.00	0.89	0.83	0.76	0.72	0.68	......	......
13	......	1.31	1.14	1.01	0.91	0.82	0.74	0.68	0.62	......	......
21	......	1.28	1.17	1.08	0.99	0.90	0.82	0.77	0.72	0.67	......
22	......	1.27	1.14	1.07	......	......	......	......	......	......	......
28	1.23	1.10	0.91	0.74	0.63	0.53	......	......	......	......	......
Means	(1.23)	1.23	1.10	0.98	0.86	0.77	0.77	0.72	0.67	(0.67)	......

TABLE 1.—*Solar radiation intensities at Mount Weather, Va., during April, May, and June, 1914*—Continued.

Date.	Air masses.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0.	5.5	6.0
1914. A. M.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
May 11	......	1.17	......	......	......	......	......	......	......	......	......
14	1.31	1.20	1.07	0.92	......	......	......	......	......	......	......
15	1.10	1.00	0.98	0.80	0.73	......	......	......	......	......	......
16	1.27	1.08	0.92	0.81	0.71	0.61	0.52	0.46	0.42	0.38	0.33
18	1.28	1.09	0.93	0.79	......	......	......	......	......	......	......
19	1.10	1.01	0.88	0.79	0.70	0.63	0.57	0.52	0.47	0.42	......
20	0.99	0.86	0.68	0.58	0.50	0.42	0.36	0.31	0.27	......	......
21	1.12	0.85	0.70	0.61	0.54	0.48	0.43	0.38	0.32	......	......
23	......	......	0.91	......	......	......	......	......	......	......	......
25	......	0.87	......	......	......	......	......	......	......	......	......
26	1.02	0.76	0.62	......	......	......	......	......	......	......	......
27	......	......	......	......	0.66	0.56	......	......	......	......	......
Means	1.15	0.99	0.85	0.76	0.64	0.54	0.47	0.42	0.37	(0.40)	(0.33)
P. M.											
May 7	......	1.24	......	......	......	......	......	......	......	......	......
12	1.33	1.07	......	......	......	......	......	......	......	......	......
16	......	1.06	0.89	0.75	0.66	0.58	0.50	0.45	0.43	......	......
17	......	......	0.76	0.68	0.60	0.53	0.47	0.42	0.38	......	......
18	......	1.10	0.95	0.83	0.73	0.65	0.58	0.52	0.47	0.43	......
19	......	0.91	0.80	0.70	0.58	0.52	0.48	......	......	......	......
20	......	0.87	0.68	0.53	0.47	0.38	0.33	......	......	......	......
21	......	0.88	0.56	......	......	......	......	......	......	......	......
31	......	1.28	1.12	1.01	0.91	0.84	0.77	......	......	......	......
Means	(1.33)	1.05	0.82	0.75	0.66	0.58	0.52	0.46	0.43	(0.43)	......
A. M.											
June 2	1.40	1.28	......	......	......	......	......	......	......	......	......
3	1.19	1.02	......	......	......	......	......	......	......	......	......
7	1.29	1.10	......	......	......	......	......	......	......	......	......
10	1.28	1.18	1.00	......	......	......	......	......	......	......	......
11	1.24	......	......	......	......	......	......	......	......	......	......
12	1.30	1.12	......	......	......	......	......	......	......	......	......
13	1.40	1.32	......	......	......	......	......	......	......	......	......
15	......	1.05	0.75	......	0.46	0.44	0.41	......	......	......	......
16	1.47	1.35	1.24	1.16	1.10	......	......	......	......	......	......
17	......	......	......	......	......	0.98	0.89	0.81	......	......	......
20	......	1.39	1.26	1.13	1.05	0.98	0.93	0.88	0.83	......	......
24	1.32	1.21	1.13	0.99	0.86	0.80	0.74	0.68	0.63	......	......
26	1.18	1.09	......	......	......	......	......	......	......	......	......
29	......	1.20	1.10	1.01	0.94	0.86	0.79	0.71	0.63	......	......
30	1.42	1.36	1.27	1.17	1.08	1.01	0.95	0.90	......	......	......
Means	1.32	1.21	1.11	1.09	0.92	0.84	0.78	0.80	0.70	......	......
P. M.											
June 2	......	1.12	1.03	0.89	......	......	......	......	......	......	......
12	......	0.92	......	......	......	......	......	......	......	......	......
30	......	1.21	1.07	0.95	0.83	......	......	......	......	......	......
Means	......	1.08	(1.05)	(0.92)	(0.83)	......	......	......	......	......	......

TABLE 2.—*Radiation intensities at Mount Weather, Va., expressed in scale readings of the Callendar horizontal recording pyrheliometer.*

Date.	Sun's zenith distance.							
	19.2°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°
	SOLAR RADIATION. (*Scale divisions.*)							
1914. A. M.								
May 20	36.6	22.8	13.6	7.8	6.0	4.7	2.9	2.5
May 26	34.0	20.1	11.9	7.6	4.9	3.0	2.0	1.6
June 30	47.2	33.2	23.7	16.7	13.0	9.9	7.5	6.3
	SKY RADIATION.							
May 20	11.1	10.0	8.4	7.1	6.3	5.3	5.2	5.0
May 26	12.0	10.6	8.7	7.1	6.1	5.1	4.6	4.0
June 30	5.1	3.7	3.6	3.3	3.2	3.0	2.8	2.6
	TOTAL RADIATION.							
May 20	47.7	32.8	22.0	14.9	12.3	10.0	8.1	7.5
May 26	46.0	30.7	20.6	14.7	11.0	8.1	6.6	5.6
June 30	52.3	36.9	27.3	20.0	16.2	12.9	10.3	8.9

The decrease in direct solar radiation was accompanied by an increase in diffuse sky radiation, as is shown by the Callendar pyrheliometer measurements given in Table 2. May 20 and 26 were smoky days, and June 30 was an unusually clear day. There were practically no clouds on these three days before noon. The measurements were obtained as described and illustrated on pages 139 and 140 of the current volume of this Review.

The Callendar records indicate that from sunrise to noon on June 30 the sky radiation was 12 per cent of the total radiation, while on May 20 and 26 it was 32 per cent and 36 per cent, respectively.

The skylight polarization, measured at a point 90° from the sun and in the same vertical circle, with the sun at zenith distance 60°, was 31 per cent on May 20, 26 per cent on May 26, and 63 per cent on June 30.

It is no doubt due to the hygroscopic character of the particles constituting the smoke that its depleting effect on solar radiation was more marked during the morning, when the air temperature was low, than during the afternoon, when the air was warmer.

PHOTOMETRIC MEASURES OF THE ZODIACAL LIGHT.

By MAXWELL HALL.

[Dated Jamaica, W. I., June 5, 1914.]

1. In a former article on the zodiacal light [1] it was stated that a few observations had been made of the intensity of the light at different distances from the sun, as compared with the light of the sky at the same zenith distance at places as free from stars as possible; more observations of this character were made this year between February 19 and April 26, 1914, when the appearance of the young moon in the west and the commencement of the "May rains" put an end to the series which included both the clearest nights and the greatest brilliancy of the eastern branch of the zodiacal light, as seen in the evening in the west.

The reduction of the observations was commenced about the beginning of April, and although the measures forming any set were as a rule as uniform as could be expected, yet the resulting illuminations were discordant. However, by going through the original observations carefully, by striking out two sets which should not have been made, and by giving weights to all the remaining sets, results were obtained sufficiently good to compare with theory.

The instrument used was a dark-glass wedge about 4½ inches in length attached to the end of a small brass tube about 3½ inches in length and an inch in diameter; the tube was, of course, blackened inside, with a diaphragm near the wedge end so that the field in looking through the other end was as much as 6° in diameter; this reduced the light of the sky at night to a circular patch apparently no larger than the full moon near the zenith. The sharp edge of the tube completely enclosed the eye, thereby cutting off all side light, and the wedge could be easily moved by hand; light was required to read on a scale the position of the wedge which gave extinction of the circular patch, and repeated readings were alternately taken of the zodiacal light at a certain point in its axis, and of the light of the sky about the same altitude as free from the brighter stars as possible.

[1] Bulletin, Mount Weather Observatory, Washington, 1914, **6**, pt. 3, p. 69.

Let m and m' be the magnitude of two stars at the same zenith distance, so that their reduction to the zenith is the same; let l and l' be their light, and r and r' their extinction readings on the wedge photometer; then

$$m'-m=c(r-r')=2.5 \log \frac{l}{l'},$$

where c is constant for the particular instrument used. Thus

$$\log \frac{l}{l'}=0.4c(r-r');$$

and by observations made of several pairs of stars it was found that $0.4c=0.18$.

Let S_0 be the light of the sky at 30° or more above the horizon on an average fine dark starlight night and r_0 its extinction reading; let S be the light at any time and r_s its reading; then

$$\log \frac{S}{S_0}=0.18\ (r_s-r_0).$$

We shall take S_0 as unity and measure all such light in terms of S_0. The corresponding value of r_0 was taken to be 5.7.

Let L be the illumination at any point in the central axis of the zodiacal light, reduced to the zenith, and let R be the reducing factor; so that $\frac{L}{R}$ is the apparent light at the point in question and $\frac{L}{R}+S$ is the whole illumination of the field of view. We thus get

$$\log \left(\frac{\frac{L}{R}+S}{S}\right)=0.18(r-r_s),$$

where r is the extinction reading of the zodiacal light. This may be written

$$\log \left(\frac{L}{RS}+1\right)=0.18(r-r_s),$$

and we thus get $\frac{L}{RS}$, or N, a known quantity. Finally,

$$\log L=\log N+\log R+\log S \qquad (1)$$

For $\log R$, Seidel's table of the extinction of light by the atmosphere [2] increased by ⅛ is used; this gives the magnitudes of stars down to 3° or 4° above the horizon to the nearest tenth of a magnitude (using the Revised Harvard Photometry) by a highly refined method adopted at Kempshot, so that it is absolutely correct for the present rough measurements, and, of course, $\log S=0.18(r_s-5.7)$.

The observations and their reductions will be found at the end of this article as formed into groups at different angular distances from the sun. The following are the general results:

Distance from sun. α	Light. L.
35°	7.2 ±0.7
50°	2.4 ±0.3
75°	1.1 ±0.1
100°	0.71±0.2
155°	0.25±0.03
180°	0.42±0.05

It is, however, important that we should obtain L along a line of sight as near the sun as possible, and the

[2] Phil. trans., London, 1873. Seidel's table enlarged is given as Table 5 at the end of this article.

following observations, recorded in the former article, allow us to approach within 21° of the sun.

Date. 1912.	Distance from sun. α	Elevation above horizon.
Sept. 11	20°	3°
23	24°	5°
Oct. 19	20°	3°
20	21°	3°
Means	21°	4°

On these and other occasions it was noticed that the illumination was fairly uniform from about 15° above the horizon down to near the horizon itself. But a point 35° from the sun would be 18° above the horizon when a point 21° from the sun would be 4° above; so that

$$\frac{\text{Light at } 21° \text{ reduced to zenith}}{\text{Light at } 35° \text{ reduced to zenith}}=\frac{R \text{ at } 86° \text{ zen. dist.}}{R \text{ at } 72° \text{ zen. dist.}},$$

so that L at 21° is about 4 times the value of L at 35°, or about 29.

The observed breadth of the zodiacal light at 21° was 32°, but the absorption of the atmosphere will have some effect on its breadth at the small altitude of 4° above the horizon. If 0.2 be the limit at the extreme edge, light amounting to 1.5 has been extinguished at the edge, so that the whole breadth has been diminished by about a tenth, and the true breadth is 35°.

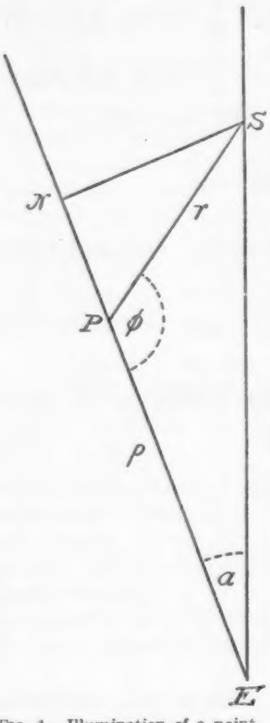

FIG. 1.—Illumination of a point, P, in the zodiacal light, seen from the earth, E, for large values of α.

2. These results naturally lead us to theoretical considerations, and we shall now determine the law of density along the central plane of the zodiacal light which will give the same values of L as those found by observation, or rather, we shall show that this density varies inversely as the square of the distance from the sun.

In figure 1, let the plane of the paper coincide with the central plane of the zodiacal light. Let S and E be the sun and earth, and let P be any point along the line of sight EP.

Taking the length SE as unity, let $SP=r$, $EP=\rho$, and let $\angle SEP=\alpha$, and $\angle SPE=\phi$.

Now considering a single spherical body at P, the illumination of the body would vary as $\frac{1+\cos\phi}{r^2\rho^2}$; but when there are a large number of small bodies their number in the field of view will vary as ρ^2, and also as the density, or their number in an unit volume of space; and as this density is assumed to vary as $\frac{1}{r^2}$ we get

$$\text{Illumination at } P=k\left(\frac{1+\cos\phi}{r^4}\right),$$

where k is some constant. And if L be the whole illumination along EP to the boundary of the zodiacal light,

$$L=k\int_0^{\rho_1}\left(\frac{1+\cos\phi}{r^4}\right)d\rho$$

where ρ_1 is the limiting length of ρ.

In order to integrate, change the independent variable from ρ to ϕ by means of the equations

$$r\sin\phi=\sin\alpha$$
$$\rho\sin\phi=\sin(\alpha+\phi),$$
$$\frac{d\rho}{d\phi}=-\frac{\sin\alpha}{\sin^2\phi}.$$

Thus

$$L=-\frac{k}{\text{in}^3\,\alpha}\int_{\pi-\alpha}^{\phi_1}(1+\cos\phi)\sin^2\phi\,d\phi;$$

and integrating,

$$L=\frac{k}{\sin^3\alpha}\left[\tfrac{1}{2}\phi-\tfrac{1}{4}\sin 2\phi+\tfrac{1}{3}\sin^3\phi\right]_{\phi_1}^{\pi-\alpha} \qquad (2)$$

where ϕ_1 is the limiting value of ϕ corresponding to ρ_1, the limiting value of r being 2.1 according to the former article.

But when P is in opposition to the sun, $\alpha=180°$, or π in circular measure; and we must now take r as the independent variable; so that

$$L \text{ at opposition}=2k\int_1^r\frac{dr}{r^4}=\frac{2k}{3}\left[\frac{1}{r^3}\right]_{2.1}^1$$

or $0.59k$.

We have now to compute L for the different values of α by means of equation (2), taking $k=0.80$ so as to suit the observed light at $\alpha=35°$ and $\alpha=50°$ as nearly as possible. The following are the results:

α	L computed.
21°	27.
35	6.6
50	2.7
75	1.1
100	0.72
155	0.49
180	0.47

The agreement between computation and observation is remarkable, and it proves the truth of the assumption as to the law of density. The computations are given at the end of this article.

3. But as the distance r decreases there must be some limit to the density, and also to the illumination. We know that the light does not greatly increase, because it is not seen during total solar eclipses; nor is it seen during twilight.

If we compute L for $\alpha=10°$ we get $L=240$, which is far beyond the scope of the instrument described above, which can only measure up to $L=13$ or 14; and twilight photometry will require another instrument and a special investigation.

Let us now suppose that the stratum constituting the zodiacal light does not approach the sun nearer than $r=0.358$, corresponding to $\alpha=21°$; the line of sight for $\alpha=10°$ now cuts the limiting circle (see fig. 2), and the integral for L consists of two parts whose sum gives us only 13.

This shows the great effect of the central condensation and the possibility of finding the interior limit of the zodiacal stratum at some future time.

The computations are given at the end of this article.

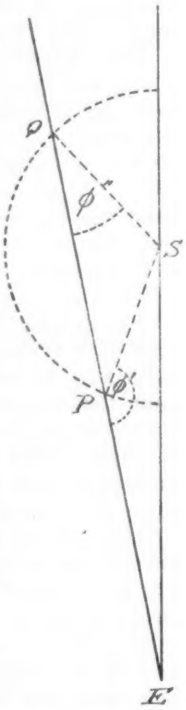

FIG. 2.—Illumination of a point, P, in the zodiacal light, seen from the earth, E, for smaller values of α.

4. We have now to consider the apparent breadth of the zodiacal light as seen from the earth, and the thickness of the stratum of the particles composing it.

With reference to the observed breadths at certain distances from the sun given in the former article p. 64, if we draw a curve through them as in figure 3 we can

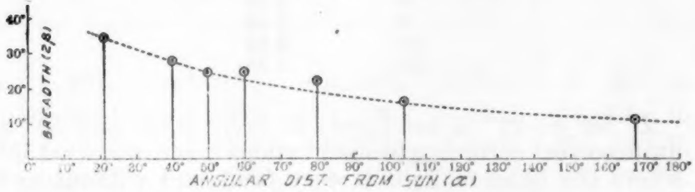

FIG. 3.—Observed breadths, 2β, of the zodiacal light for different values of α.

take from that curve the "observed" breadth at any distance from the sun, and thus get the following half-breadths, which we shall call β.

α	β
°	°
21	17½
35	15
50	13
75	10
100	8
155	6
180	6

In figure 1 draw SN at right angles to EP, so that $SN=r=\sin\alpha$, and $EN=\rho=\cos\alpha$; and let us consider a section of the stratum along the line EN by a plane at right angles to the paper. Let $2h$ be the whole thickness of the stratum at N, so that $h=\rho\tan\beta$.

If we now combine r, ρ, and h at $\alpha=21°$, $35°$, and $50°$, we come to the conclusion that the stratum has a curved surface so that h is greatest when r is least, and so that $h=\dfrac{0.115}{r}$.

The following are the computations:

TABLE 1.—*Computation of* hr.

α	β	r	ρ	h	hr
°	°				
21	17½	0.358	0.934	0.294	0.106
35	15	0.574	0.819	0.220	0.126
50	13	0.766	0.643	0.148	0.114
Mean..	....	....	....	....	0.115

We can go no further than $\alpha=50°$, for as α approaches and exceeds 90° the conditions entirely change; but we can find the relation between r, ρ, and h for any value of α and the corresponding β.

Let r_2, ρ_2, h_2, have the special values which satisfy the given values of α and β; then

$$r_2\rho_2=\frac{0.115}{\tan\beta},$$

and as

$$r_2\rho_2=\frac{\sin\alpha\sin(\alpha+\phi_2)}{\sin^2\phi_2},$$

we have

$$\frac{\sin(\alpha+\phi_2)}{\sin^2\phi_2}=\frac{0.115}{\sin\alpha\tan\beta},$$

an equation which can easily be solved by approximation.

A small difficulty occurs for $\alpha=180°$ because $\sin\alpha$ and $\sin\phi_2$ both vanish; but we have only to find the limiting value of

$$\frac{\sin\alpha\sin(\alpha+\phi_2)}{\sin^2\phi_2}.$$

In figure 1 let $\angle ESP=\psi$; then $\phi_2=\pi-(\alpha+\phi_2)$; and the expression becomes

$$\frac{\sin\alpha\sin(\pi-\psi)}{\sin^2(\alpha+\psi)};$$

and putting $\psi=0$, and $\alpha=\pi$, the limiting value is 1; so that $r_2\rho_2=1$; but as the tangent of 6° is 0.105, $r_2\rho_2\tan\beta=0.105$; and the constant is 0.105 for this end of the curve, while we found 0.115 for the other end.

Consequently we shall take the constant to be 0.110, and consider that the equation

$$h=\frac{0.110}{r} \tag{3}$$

is true for the whole series. The equation for ϕ_2 is now

$$\frac{\sin(\alpha+\phi_2)}{\sin^2\phi_2}=\frac{0.110}{\sin\alpha\tan\beta'}$$

and the computations are here given.

TABLE 2.—*Computation of* r_2, ρ_2, *and* h_2.

α	β	$\dfrac{0.110}{\sin\alpha\tan\beta}$.	ϕ_2	r_2	ρ_2	h_2
°	°		° ′			
21	17½	0.974	84 22	0.360	0.969	0.306
35	15	0.716	101 37	0.586	0.701	0.188
50	13	0.622	91 33	0.766	0.622	0.144
75	10	0.646	70 8	1.027	0.608	0.107
100	8	0.795	51 10	1.264	0.619	0.087
155	6	2.476	15 12	1.612	0.649	0.068
180	6	....	....	1.640	0.640	0.067

Let us now take a section passing through the sun by a plane at right angles to the paper, as along the line SN produced in figure 1. In the following figure, which represents the section of the northern half of the western branch, S is the sun, SA the central axis of the zodiacal light, M any point on the bounding curve LM; so that $SN=r$, and $MN=h$.

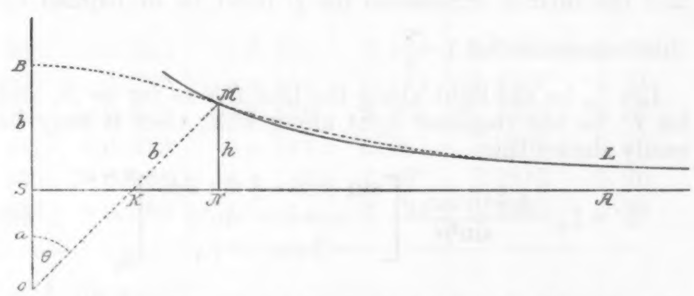

FIG. 4.—Section of the northern half of the western branch of the zodiacal light. S the sun, SA the central axis of the zodiacal light, M any point on the bounding curve, $SN=r$.

Now, provided we do not approach the sun nearer than $\alpha=21°$ or $r=0.358$, the curve given by equation (3) practically agrees with the conchoid of Nicomedes taking $a=0.265$ and $b=0.326$; this is the dotted curve in figure 4 to distinguish it from the former continuous curve; and nothing could have been more useful than this connection if we had to approach the sun, which is more than a matter of doubt; but, on the other hand, the conchoid complicates the relation between h and r to such an extent as to be almost useless among forms for integration.

Thus the polar equation of the conchoid is

$$\text{Radius} = a \sec \theta + b;$$

but retaining the former origin and rectangular coördinates

$$h = b \cos \theta,$$
$$r = a \tan \theta + b \sin \theta,$$

so that

$$r = \left(\frac{a+h}{h}\right)\sqrt{b^2 - h^2};$$

and we shall continue to use equation (3).

5. We must now consider the decrease in the density with the height of any point above the central plane. In figure 4 take any point between N and M at a distance z from N; now we have found that the density at N varies inversely as r^2, and we shall find that the density at the point above N further varies inversely as z, so that

$$\frac{\text{density at point}}{\text{density at } N} = 1 - \frac{z}{h}$$

and we proceed to compute the illumination at such a point as M on the boundary of the zodiacal light as seen from the earth for the different values of α and their corresponding values of β.

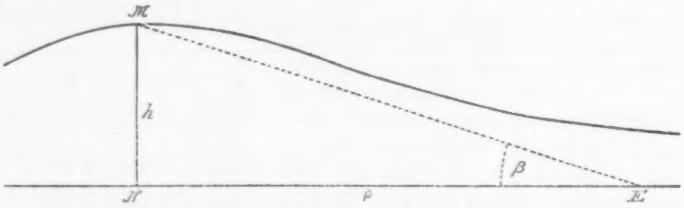

FIG. 5.—A section of the stratum along the line EPN of fig. 1, when $\alpha = 21°$ and $\beta = 17\frac{1}{2}°$. The line of sight cuts the surface at M.

Figure 5 is a section of the stratum along the line EPN in figure 1, where $\alpha = 21°$ and $\beta = 17\frac{1}{2}°$; and it will be seen that the line of sight cuts the surface at M, so that in integrating along EM the limits are ρ_2 and ϕ_2 corresponding to N.

$$\text{Now } 1 - \frac{z}{h} = 1 - \frac{r\rho \tan \beta}{0.110}$$

$$\text{so that } 1 - \frac{z}{h} = 1 - 9.09 \tan \beta . \frac{\sin \alpha \sin(\alpha + \phi)}{\sin^2 \phi}$$

and the former expression for L must be multiplied by this expression for $1 - \frac{z}{h}$

Let L_2 be the light along the line EN as far as N, and let L' be the required light along EM; then it may be easily shown that

$$L' = L_2 - \frac{4.54k \tan \beta}{\sin^2 \alpha}\left[\begin{matrix} \sin \alpha(\phi + \frac{1}{2} \sin 2\phi) \\ + \cos \alpha \sin^2 \phi \\ -2 \cos(\alpha + \phi) \end{matrix}\right]_{\phi_2}^{\pi - \alpha} \qquad (4)$$

where the limits for L_2 are of course also $\pi - \alpha$ and ϕ_2. The computations are given further on, and the results are:

α °	L'
21	0.92
35	0.21
50	0.22
75	0.26
100	0.28
155	0.30

L' for $\alpha = 21°$ is too large; L' for $\alpha = 35°$ and $50°$ is quite correct according to observations made near $\alpha = 155°$ where the band of light is very faint and without any distinct central condensation, as is also shown by the computed values of L and L' for $\alpha = 155°$.

There is no difficulty about L' for $\alpha = 21°$; a revision of this article would probably put it right.

6. There are also other matters which should receive attention at some future time; the integrals for L do not show the "gegenschein" or counterglow, the small effect of phase near the earth being effaced by the very great distances involved.

Perhaps we should consider the reflection from a certain proportion of bright metallic particles, producing an effect similar to the "anthelion" [glory] which surrounds an observer's head on a dewy lawn under well-known circumstances.

Then there is the question of mass and possible small perturbations. Let m be the whole mass of the particles constituting the zodiacal light; then if D and h be the density and half the thickness at unit distance, and taking 2.1 and 0.3 as the limits of r, we have $m = 6\pi Dh$, nearly.

And for the mass interior to the planets we have

	Interior mass.
Mars	$0.9\,m$
The Earth	$0.8\,m$
Venus	$0.7\,m$
Mercury	$0.3\,m$

This shows that there is a very slight increase in the central attraction from Mercury outwards.

Again, in the case of Mercury more particularly, the interior mass may be regarded as a ring at a certain distance from each planet; and with a for each planet, $e = 0$, $i = 1° 35'$, $\Omega = 107°$, we might estimate the secular perturbations of the elements of each planet. For instance, if this ring within the orbit of Mercury was the disturbing cause of the motion of its perihelion which was required by Leverrier many years ago, the mass within the orbit would be about one-third that of Mercury, and therefore m would be about equal to that of Mercury itself.

TABLE 3. A.—*The computation of* L.

α	$\phi=\pi-\alpha$				ϕ_1	$\phi=\phi_1$				$\log \frac{k}{\sin^3\alpha}$	L
	$\frac{1}{2}\phi$	$-\frac{1}{2}\sin 2\phi$	$+\frac{1}{3}\sin^3\phi$	Sum.		$\frac{1}{2}\phi$	$-\frac{1}{2}\sin 2\phi$	$+\frac{1}{3}\sin^3\phi$	Sum.		
°					° ′						
21	1.3875	+0.1673	+0.0153	1.5701	9 50	0.0858	−0.0841	+0.0017	0.0034	1.2401	27.
35	1.2654	+0.2349	+0.0629	1.5632	15 51	0.1383	−0.1314	+0.0068	0.0137	0.6273	6.6
50	1.1345	+0.2462	+0.1499	1.5306	21 24	0.1868	−0.1699	+0.0162	0.0331	0.2503	2.7
75	0.9163	+0.1250	+0.3004	1.3417	27 23	0.2390	−0.2042	+0.0324	0.0672	$\bar{1}$.9483	1.1
100	0.6981	−0.0855	+0.3183	0.9309	27 58	0.2440	−0.2071	+0.0344	0.0713	$\bar{1}$.9231	0.72
155	0.2182	−0.1915	+0.0252	0.0519	11 37	0.1014	−0.0986	+0.0027	0.0055	1.0253	0.49

B.—*The computation of* L_2.

α	$\phi=\pi-\alpha$				ϕ_2	$\phi=\phi_2$				$\log \frac{k}{\sin^3\alpha}$	L_2
	$\frac{1}{2}\phi$	$-\frac{1}{2}\sin 2\phi$	$+\frac{1}{3}\sin^3\phi$	Sum.		$\frac{1}{2}\phi$	$-\frac{1}{2}\sin 2\phi$	$+\frac{1}{3}\sin^3\phi$	Sum.		
°					° ′						
21	1.3875	+0.1673	+0.0153	1.5701	84 22	0.7362	−0.0488	+0.3286	1.0160	1.2401	9.632
35	1.2654	+0.2349	+0.0629	1.5632	101 37	0.8868	+0.0986	+0.3133	1.2987	0.6273	1.121
50	1.1345	+0.2462	+0.1499	1.5306	91 33	0.7989	+0.0135	+0.3330	1.1454	0.2503	0.686
75	0.9163	+0.1250	+0.3004	1.3417	70 8	0.6120	−0.1598	+0.2773	0.7295	$\bar{1}$.9483	0.544
100	0.6981	−0.0855	+0.3183	0.9309	51 10	0.4465	−0.2442	+0.1576	0.3599	$\bar{1}$.9231	0.478
155	0.2182	−0.1915	+0.0252	0.0519	15 12	0.1327	−0.1265	+0.0060	0.0122	1.0253	0.421

C.—*The computation of* L′.

α	$\phi=\pi-\alpha$				ϕ_2	$\phi=\phi_2$				$\log \frac{4.54\,k\tan\beta}{\sin^2\alpha}$	L′
	$\sin\alpha\times(\phi+\frac{1}{2}\sin 2\phi)$	$\cos\alpha\times\sin^2\phi$	$-2\cos(\alpha+\phi)$	Sum.		$\sin\alpha\times(\phi+\frac{1}{2}\sin 2\phi)$	$\cos\alpha\times\sin^2\phi$	$-2\cos(\alpha+\phi)$	Sum.		
°					° ′						
21	0.874	+0.120	+2	2.994	84 22	0.563	+0.925	+0.530	2.018	0.9502	0.92
35	1.182	+0.270	+2	3.452	101 37	0.904	+0.786	+1.454	3.144	0.4710	0.21
50	1.361	+0.377	+2	3.738	91 33	1.203	+0.642	+1.566	3.411	0.1551	0.22
75	1.529	+0.242	+2	3.771	70 08	1.491	+0.229	+1.641	3.361	$\bar{1}$.8366	0.26
100	1.543	−0.168	+2	3.375	17 10	1.360	−0.105	+1.752	3.007	$\bar{1}$.7213	0.20
155	0.346	−0.162	+2	2.184	15 12	0.219	−0.062	+1.971	2.128	0.3299	0.38

D.—*The two computations of* L *for* $\alpha=10°$.

$\alpha=10°$; $\phi_1=4°\ 45'$; $\phi'=151°\ 0'$; $\phi''=29°\ 0'$.

$SP=SQ=0.358$ (see fig. 2, p. 312.) $F=\frac{k}{\sin^3\alpha}$; $\log F=2.1841$.

ϕ	$\pi-\alpha$	ϕ_1	ϕ'	ϕ''
$\frac{1}{2}\phi$	+1.4835	+0.0414	+1.3177	+0.2531
$-\frac{1}{2}\sin 2\phi$	+0.0855	−0.0413	+0.2120	−0.2120
$+\frac{1}{3}\sin^3\phi$	+0.0018	+0.0002	+0.0380	+0.0380
Sums	1.5708	+0.0003	+1.5677	+0.0791

$L=F\,(1.50708-0.0003)$ = 240.

Light along $EP=F(1.5708-1.5677)$ = 0.47

Light from Q outwards $=F(0.0791-0.0003)$ = 12.04

Total = 12.51

55828—14——2

TABLE 4.—*Photometric measures of the Zodiacal Light in Jamaica, W. I.*

Dist. from Sun a.	L	S	r	r_s	Zenith distance. z.	Date (civil time).	Weight.	Notes.
°					°			
39	3.6	(1)	8.6	(5.7)	67	1912, Sept. 11, 4:40 a.	1	Starlight not obs. near Z. L. Light of Z. L. suddenly increased.
35	5.7	(1)	9.0	(5.7)	74	1912, Sept. 23, 4:40 a.	1	Starlight not obs. near Z. L.
38	6.6	1.4	9.1	6.5	78	1912, Oct. 18, 4:40 a.	2	Night poor.
38	3.2	0.9	7.4	5.4	80	1913, Feb. 25, 7:40 p.	2	Recommenced observations.
34	5.6	0.9	8.5	5.5	78	1914, Feb. 19, 7:30 p.	2	Recommenced observations.
30	3.8	0.7	7.2	4.7	81	1914, Mar. 24, 7:40 p.	1	Starlight suddenly increased.
32	12.3	1.1	9.4	6.0	79	1914, Mar. 25, 7:30 p.	2	Starlight not sufficiently observed.
34	9.0	1.8	9.9	7.1	77	1914, Apr. 18, 7:30 p.	3	Starlight brilliant.
35	9.1	1.5	10.0	6.7	75	1914, Apr. 24, 7:40 p.	3	Starlight brilliant. Fine display.
54	1.5	(1)	7.7	(5.7)	55	1912, Sept. 10, 4:30 a.	2	Starlight not observed. Very clear.
41	2.0	(1)	7.7	(5.7)	67	1912, Sept. 10, 4:40 a.	2	Starlight not observed. Very clear.
55	2.2	0.8	7.2	5.3	76	1912, Sept. 10, 8:00 p.	3	
59	1.1	0.7	6.8	4.7	55	1912, Sept. 15, 4:00 a.	1	Starlight not observed near Z. L.
41	5.4	1.3	9.0	6.3	75	1912, Oct. 19, 4:20 a.	2	
42	4.4	1.1	8.6	5.9	74	1912, Oct. 20, 4:20 a.	3	Very clear, fine display of the Z. L.
57	0.8	1.3	7.2	6.3	60	1913, Feb. 24, 8:00 p.	2	Very clear, but poor display.
56	1.3	0.8	7.0	5.0	60	1913, Feb. 25, 8:00 p.	2	Very clear, fair display.
54	0.9	0.9	6.8	5.4	60	1913, Feb. 27, 8:00 p.	2	Very clear, poor display.
53	1.2	0.9	7.2	5.5	57	1913, Feb. 28, 7:30 p.	2	Very clear, poor display.
44	4.0	1.1	8.5	6.0	74	1914, Mar. 25, 7:40 p.	2	
52	2.3	1.1	8.0	6.0	70	1914, Mar. 25, 8:20 p.	2	
48	3.0	(1)	8.2	(5.7)	70	1914, Mar. 26, 7:40 p.	1	Starlight not properly obs.
67	1.7	1.3	8.2	6.3	50	1912, Sept. 23, 4:00 a.	1	Observation poor.
78	0.7	(1)	7.0	(5.7)	35	1912, Oct. 19, 4:30 a.	1	Starlight observation much too low.
70	1.0	1.1	7.3	5.9	50	1912, Oct. 20, 4:00 a.	3	
78	1.3	0.9	7.3	5.4	58	1912, Oct. 30, 8:00 p.	3	
76	1.0	1.0	7.3	5.7	48	1912, Nov. 1, 7:20 p.	3	
89	0.8	1.2	7.2	6.1	57	1912, Nov. 6, 2:30 a.	3	
60	1.7	1.4	8.2	6.5	55	1914, Mar. 28, 7:40 p.	2	
92	0.5	1.1	6.8	5.9	22	1914, Apr. 18, 7:50 p.	3	Starlight brilliant.
99	0.5	1.8	7.6	7.1	50	1914, Apr. 22, 3:40 a.	3	
108	2.0	1.2	8.4	6.2	49	1914, Apr. 24, 3:10 a.	1	Much light in sky below Sagittarius.
111	0.1	1.6	7.0	6.8	7	1914, Apr. 24, 8:00 p.	1	Near zenith, difficult to observe.
101	0.9	1.1	7.4	6.0	28	1914, Apr. 26, 9:00 p.	3	
146	0.1	0.6	4.8	4.6	32	1912, Sept. 21, 4:40 a.	1	After dawn very thin cir. str. was seen about the sky.
146	0.2	1.3	6.6	6.3	20	1912, Sept. 23, 3:50 a.	3	
151	0.1	0.9	5.6	5.4	73	1914, Mar. 28, 3:20 a.	1	Too low.
149	0.2	1.6	7.0	6.8	62	1914, Mar. 30, 2:20 a.	2	Starlight brilliant: Z. L. rather low.
167	0.2	1.1	6.3	5.9	53	1914, Apr. 18, 8:10 p.	3	Starlight brilliant.
153	0.5	1.7	7.4	7.0	66	1914, Apr. 20, 2:30 a.	3	Long series of readings.
161	0.2	1.2	6.5	6.2	42	1914, Apr. 24, 2:50 a.	2	
139	0.3	1.6	7.2	6.8	23	1914, Apr. 24, 8:20 p.	3	E branch.
167	0.2	1.4	6.9	6.6	40	1914, Apr. 25, 2:40 a.	3	W branch.
174	0.4	(1)	6.3	(5.7)	60	1912, Sept. 10, 4:20 a.	1	Starlight not observed.
171	0.4	0.5	5.5	4.2	43	1912, Sept. 11, 3:20 a.	3	
179	0.7	0.7	6.2	4.7	56	1912, Sept. 15, 3:30 a.	3	Gegenschein bright and extends 20° along ecliptic.
175	0.6	1.3	7.1	6.3	55	1912, Sept. 23, 3:40 a.	3	
174	0.4	1.2	6.8	6.2	30	1912, Nov. 6, 1:30 a.	3	
180	0.2	1.2	6.6	6.2	20	1913, Mar. 6, 1:20 a.	2	Few observations, clouds came up.
172	0.5	1.1	6.8	6.0	50	1913, Mar. 16, 4:00 a.	3	
171	0.1	1.2	6.4	6.2	52	1914, Apr. 22, 3:20 a.	3	

TABLE 5.—*Seidel's table of the extinction of light by the atmosphere, increased 1/6.*

z	log R	z	log R	z	log R	z	log R
°		°		°		°	
13	0.000	32	0.010	51	0.057	70	0.223
14	1	33	12	52	.062	71	.238
15	1	34	13	53	.067	72	.254
16	1	35	14	54	.072	73	.272
17	1	36	15	55	.078	74	.291
18	2	37	16	56	.084	75	.313
19	3	38	17	57	.090	76	.336
20	3	39	18	58	.097	77	.361
21	4	40	20	59	.105	78	.389
22	4	41	22	60	.113	79	.419
23	5	42	24	61	.121	80	.453
24	5	43	27	62	.130	81	.499
25	6	44	30	63	.141	82	.565
26	6	45	33	64	.152	83	.641
27	7	46	36	65	.163	84	.719
28	7	47	40	66	.175	85	.798
29	8	48	44	67	.187	86	.880
30	8	49	48	68	.198	87	(0.964)
31	0.009	50	0.052	69	0.210	88	(1.048)

[Some observations on the zodiacal light, made by M. J. Donovan at Vicksburg, in February, 1914, and others by William E. Barron, also at Vicksburg, were referred to Mr. Maxwell Hall, and the following comments by him show how much good work can be done by those interested in this subject. We hope that other observers who are favorably situated will take an interest in this class of observations, as it is evident that such observations must be of great value.—C. A.]

NOTES ON MR. DONOVAN'S OBSERVATION OF THE ZODIACAL LIGHT, 1914, JAN. 27, 8:45 P. M.

[Dated Jamaica, W. I., June 22, 1914.]

Drawing a line between α Arietis and α Ceti we find that the point on the central axis of the zodiacal light was in longitude 39° with a latitude of ½° S., and that its breadth was 20°. Now the sun's longitude was 307° at that time, so that this observation gives us:

Long.	39°
Lat.	$-\frac{1}{2}$°
Distance from sun	92°
Breadth	20°

According to MONTHLY WEATHER REVIEW, March, 1906, p. 4, Table 5, for long. 39° the corresponding lat. is $-1\frac{1}{4}$°; so that the above observation is as nearly correct as possible.

Again, according to *Bulletin of the Mount Weather Observatory*, v. 6, pt. 3, p. 66, Table 4, or above figure 3, page 313, the breadth at 92° from the sun is 18°; so

that the above observation is again as nearly as possible correct.

A few more of these observations made at different times of the year would have a high value.—*Maxwell Hall.*

NOTES ON MR. BARRON'S OBSERVATION OF THE ZODIACAL LIGHT.

[Dated Jamaica, W. I., June 22, 1914.]

If Mr. Barron were to procure a good set of maps and to note the position of the zodiacal light among the stars on a dark star-light night the observations he has made clearly show that his work would be of great value. He should observe as high above the horizon as possible to avoid the luminosity of the atmosphere near the horizon, which mingles with the zodiacal light and plays all kinds of tricks. Seen at its best the zodiacal light is a long tapering cone not more than 32° broad at its base, perfectly uniform and steady in figure and light; and if Mr. Barron were to start upon these lines he would soon become an expert.—*Maxwell Hall.*

SECTION II.—GENERAL METEOROLOGY.

THE DISTRIBUTION OF SNOWFALL IN CYCLONES OF THE EASTERN UNITED STATES.[1]

By CHARLES F. BROOKS.

[Dated, Harvard University, Cambridge, Mass., June 12, 1914.]

The distribution of snowfall in cyclones may be studied in a general way with weather-maps, but more in detail with the original reports of the coöperative observers of the Weather Bureau in addition. Through the kindness of Mr. P. C. Day, Chief of the Climatological Division of that bureau, the writer was enabled to examine the original records for the eastern United States covering two snowstorms, February 10–14, 1899, and February 20–23, 1912. In charting the snowfall for each day of these periods, many of the observations could not be used because the snowfall had been recorded only for the storm as a whole. However, these records were employed in drawing the charts of the total snowfall of each storm reproduced as figures 6 and 11. The daily snowfall records are homogeneous to the extent that the observations were generally taken within two or three hours of sunset each day. On account of the strong winds accompanying the two snowstorms, the snow was badly drifted and packed in many places, thus rendering the observations subject to large local errors. However, the use of 800 to 1,000 stations for each storm in preparing the charts, probably eliminated many such irregularities. These storms will be discussed in detail after a general consideration of cyclones and snowfall.

Cyclones and snowfall.

In winter most of the precipitation of the eastern United States is produced chiefly by the forced ascent of converging winds about the centers of cyclones. Loomis (1) found that the centers of the precipitation areas of cyclones generally lie near the center and on the east side or front of the cyclone. On this side the winds are rising more strongly than behind, for the cyclone, moving as a wave, meets the winds in front and draws away from those behind. Mr. W. G. Reed, in a study of the cyclonic distribution of rainfall in the United States (2), found that the area of heaviest precipitation usually occurred on the side of the cyclone track which was nearer a large source of moisture. Thus, in the eastern United States, the combined effect of the motion of the storm and the positions of the Great Lakes and Atlantic Ocean generally locates the region of greatest precipitation in the northeast quadrant of cyclones.

With proper temperature conditions the previously-mentioned distribution of precipitation applies to snowfall. Active condensation taking place below 32° F. forms snow crystals, which reach the ground if they are not entirely melted or evaporated on the way. Mr. W. A. Bentley of Jericho, Vt., has made a great many photomicrographs of snow-crystals (3). He classified these not only according to form but also on the basis of their cloud associations and the cyclonic quadrant in which they occurred. The two principal forms of snow-crystals are the tabular and the branching, stellate forms. The former seem to be associated with the upper clouds and the latter with the lower ones. Perfect crystal forms occur most frequently in the west half of the cyclone. In the east half broken and unsymmetrical forms are produced by turbulent winds and melting. Many flakes passing through clouds of undercooled liquid drops become coated with granular ice and fall to the earth rapidly. A similar heaviness is produced when snowflakes partly melt in a warm stratum and freeze in a cold layer of air. In the center of a cyclone, all forms may occur.

Turning now to snowfall amounts, in the region of the warm southerly winds on the southeast side of a cyclone, heavy snowfall does not usually occur. Thus snowstorms in the eastern United States are generally confined to the northwest halves of cyclones. The heaviest snowfall occurs as near the center and as much to the northeast as temperatures permit. Any melting of the snow in the air or on the ground reduces the apparent depth of snowfall. So the greatest depth of snowfall is not necessarily reported from the region of greatest precipitation in the form of snow, but generally from farther north where with perhaps less precipitation the snow-cover formed was less dense.

This cyclonic distribution of snowfall is strongly modified by local topography. Winds blowing from water to land in winter are cooled in several ways: (1) by radiation to the cold land—or snow—surface; (2) by mixture with cold air; (3) by expansion in forced ascent, when friction diminishes the wind velocity and when the winds are forced to rise with increasing altitude of the land. Such effects tend to intensify cyclonic snowfall or to cause snowfall beyond the limits of the precipitation produced by cyclonic action. Thus, the immediate leeward shores usually have more snow than areas a short distance inland. The expansion of air rising on the windward sides of mountains also augments cyclonic snowfall. The warming by compression as the wind descends on the leeward sides has the opposite tendency.

Snow storm of February 10–14, 1899.

The two snowstorms shown on the appropriate weather-maps and the accompanying charts are intense examples of the usual distribution of snowfall in winter cyclones. The storm of February 10–14, 1899 was preceded by very cold weather over the central and northeastern United States. As a result of the strong temperature gradient between the Central States and the Gulf of Mexico, a convectional circulation was established in which a cyclone gradually developed. This cyclone moved from Florida northeastward, sweeping the entire Atlantic coast with its northwestern half. On account of the accompanying low temperatures, the precipitation was mostly snow. (See the Daily Weather Map of the United States for the dates in question.)

Figure 1 shows the snowfall from sunset February 9 to sunset February 10, 1899. The snowfall indicated in the Lake region was locally produced by the on-shore winds from the Lakes. That of the central Mississippi and lower Ohio valleys was probably the result of weak cyclonic action. The snowfall of the Gulf States occurred in the southern convectional circulation. The next day

[1] This work was presented as part of the requirements for the degree of Doctor of Philosophy in Climatology at Harvard University, May, 1914.

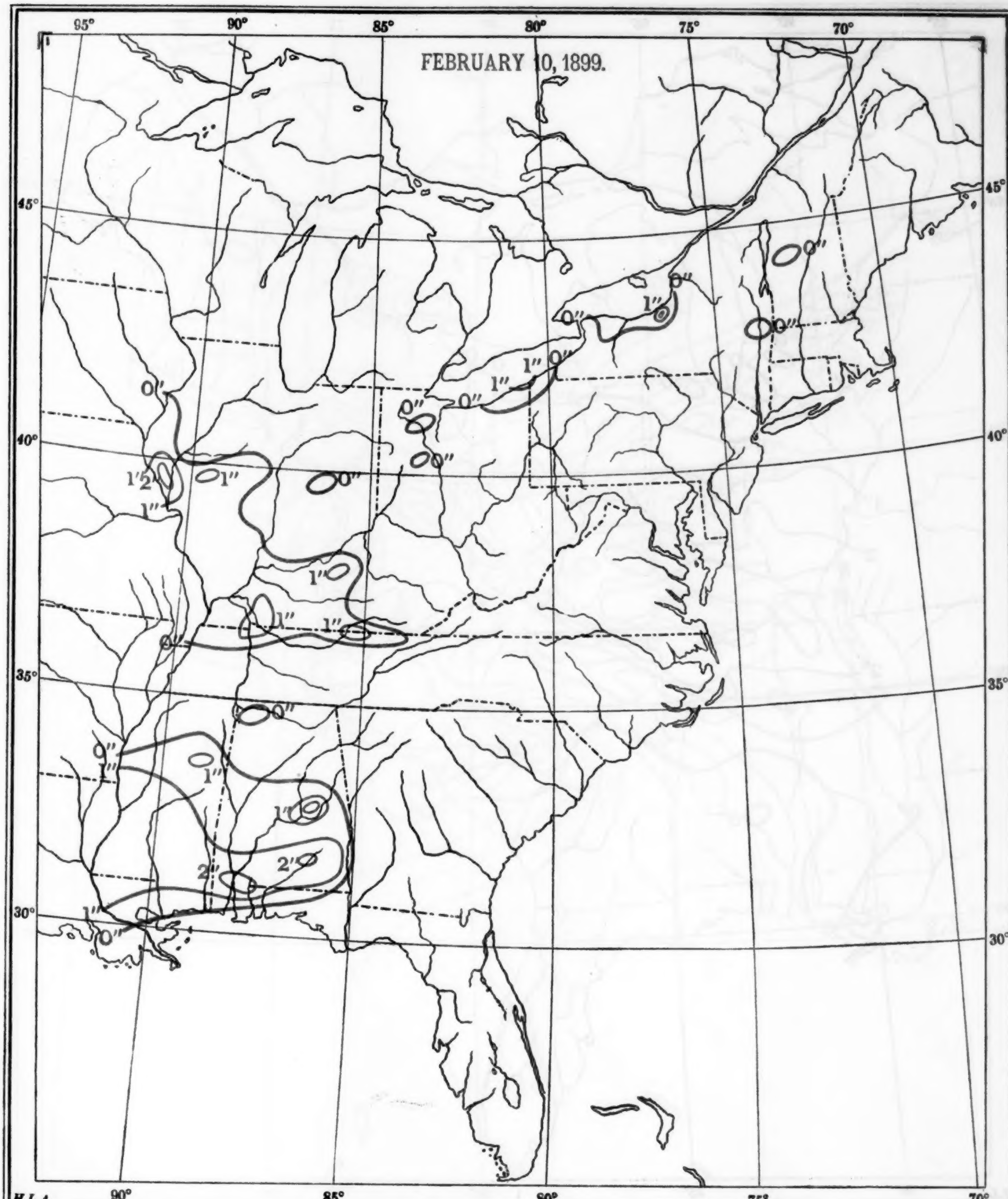

FIG. 1.—Snowfall over the eastern United States from sunset on February 9 to sunset on February 10, 1899. (Depths in inches.)

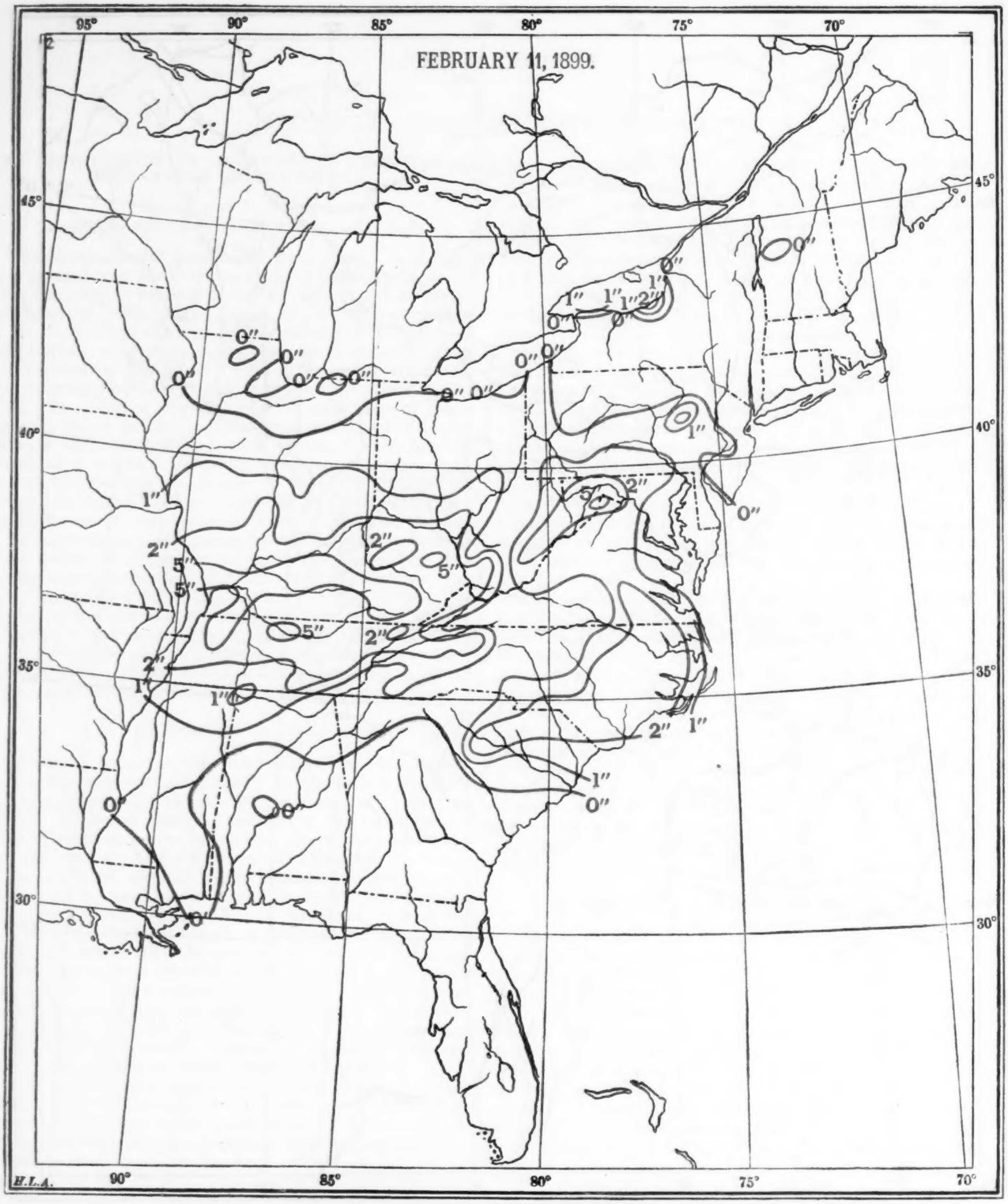

FIG. 2.—Snowfall over the eastern United States from sunset on February 10 to sunset on February 11, 1899. (Depths in inches.)

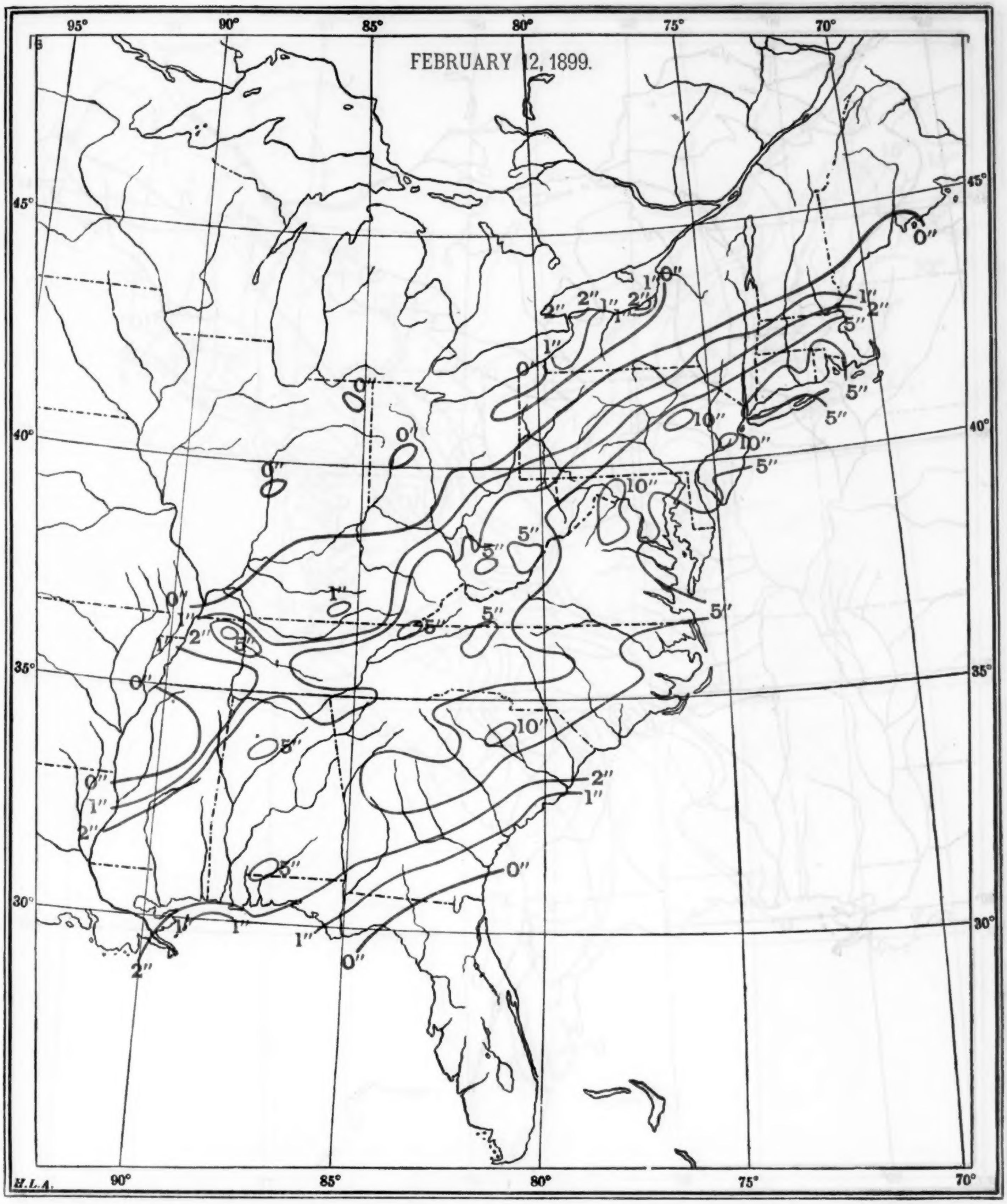

FIG. 3.—Snowfall over the eastern United States from sunset on February 11 to sunset on February 12, 1899. (Depths in inches.)

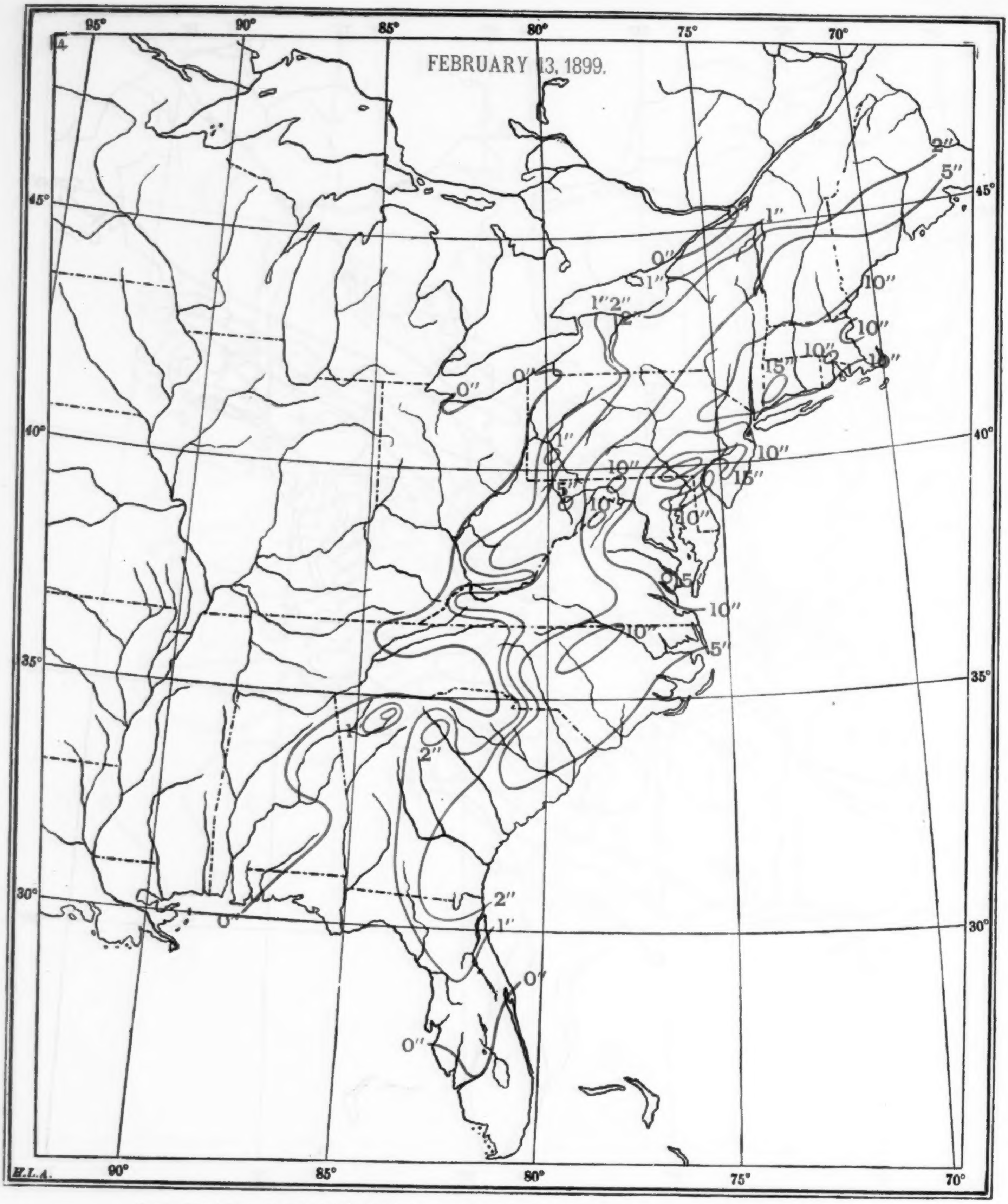

FIG. 4.—Snowfall over the eastern United States from sunset on February 12 to sunset on February 13, 1899. (Depths in inches.)

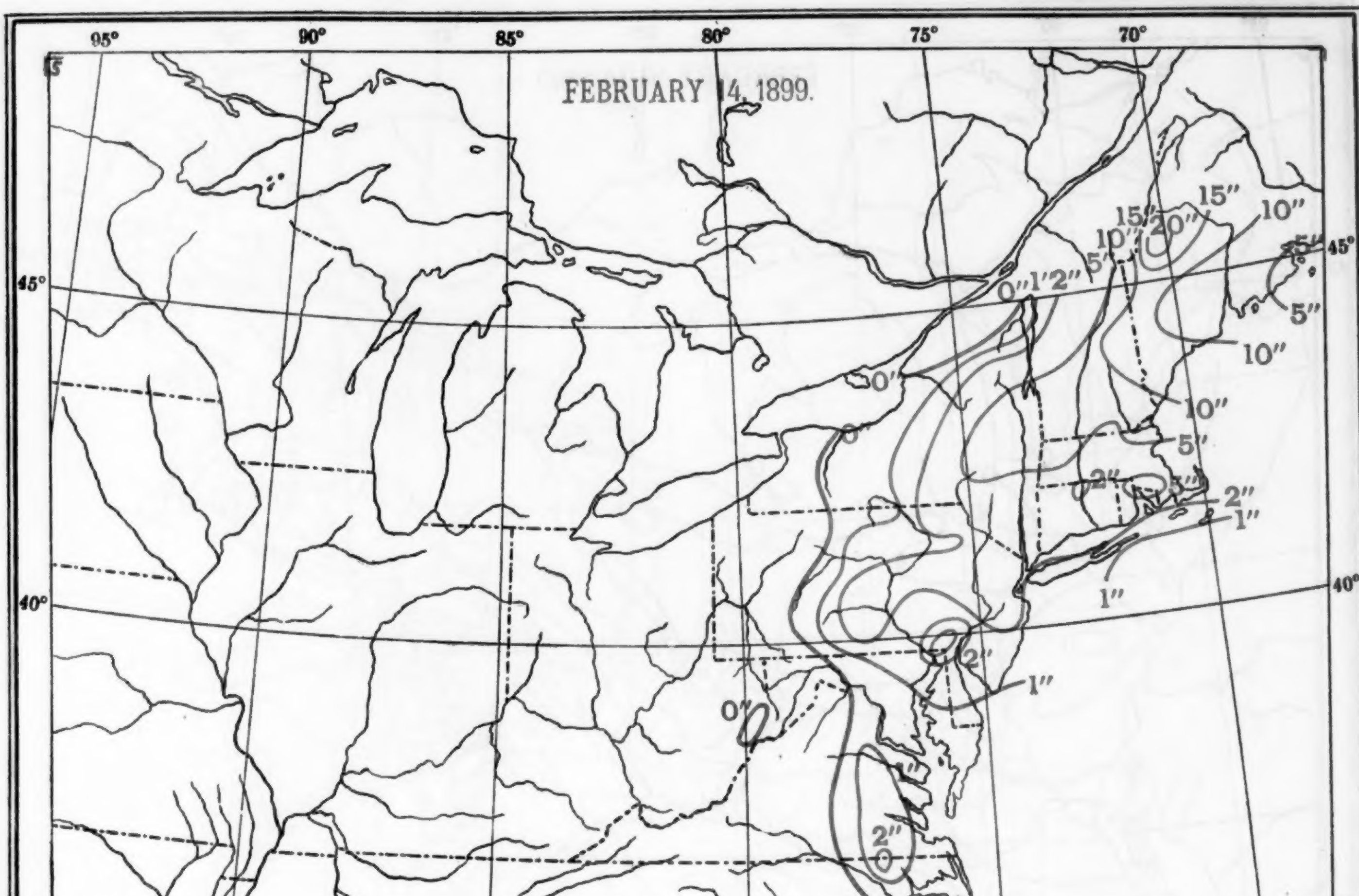

FIG. 5.—Snowfall over the eastern United States from sunset on February 13 to sunset on February 14, 1899. (Depths in inches.)

FIG. 6.—Total snowfall over the eastern United States for the storm of February 10-14, 1899. Two maxima of 44 inches each occurred in south-central New Jersey and in southeastern Pennsylvania. (Depths in inches.)

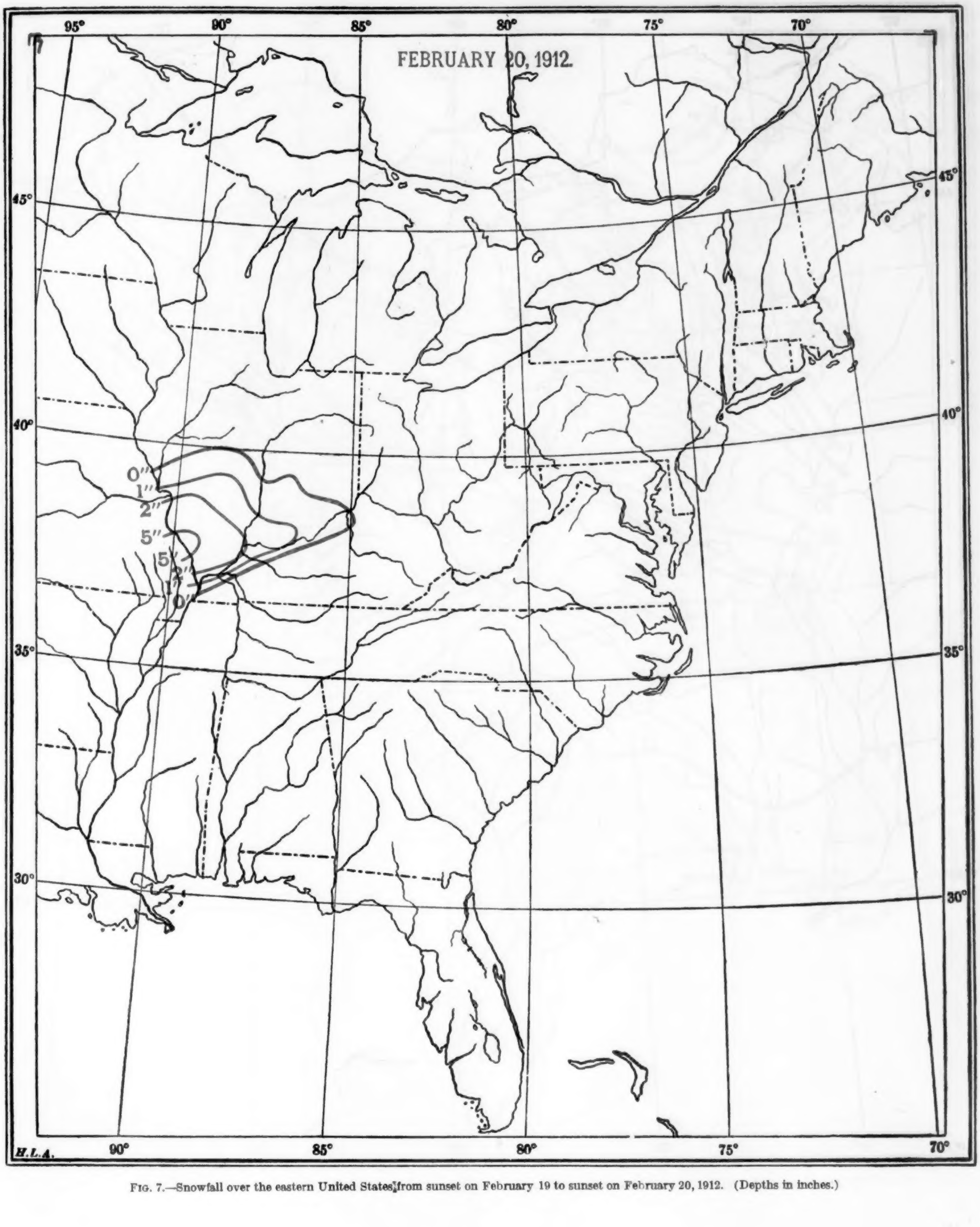

FIG. 7.—Snowfall over the eastern United States from sunset on February 19 to sunset on February 20, 1912. (Depths in inches.)

FIG. 8.—Snowfall over the eastern United States from sunset on February 20 to sunset on February 21, 1912. (Depths in inches.)

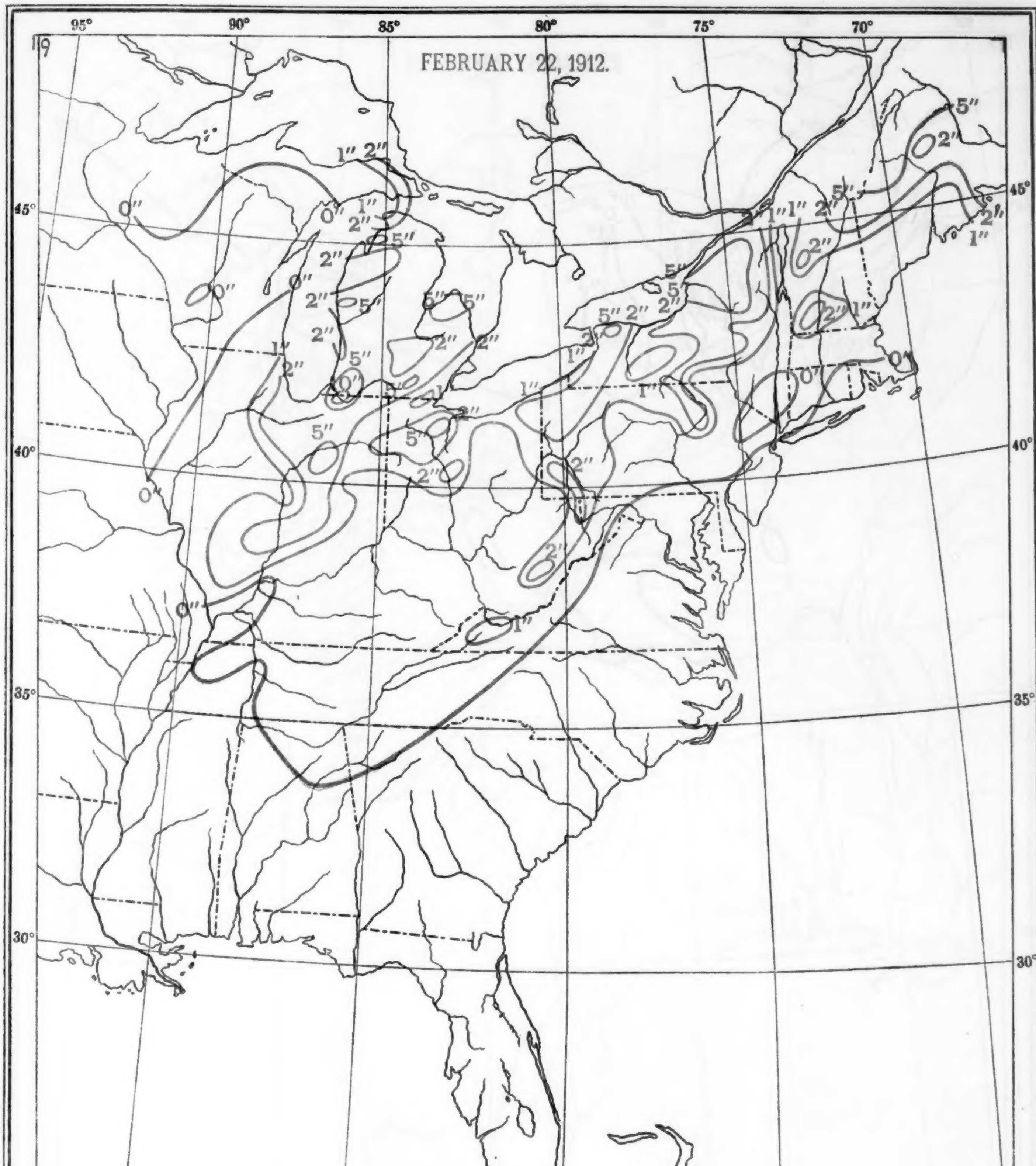

FIG. 9.—Snowfall over the eastern United States from sunset on February 21 to sunset on February 22, 1912. (Depths in inches.)

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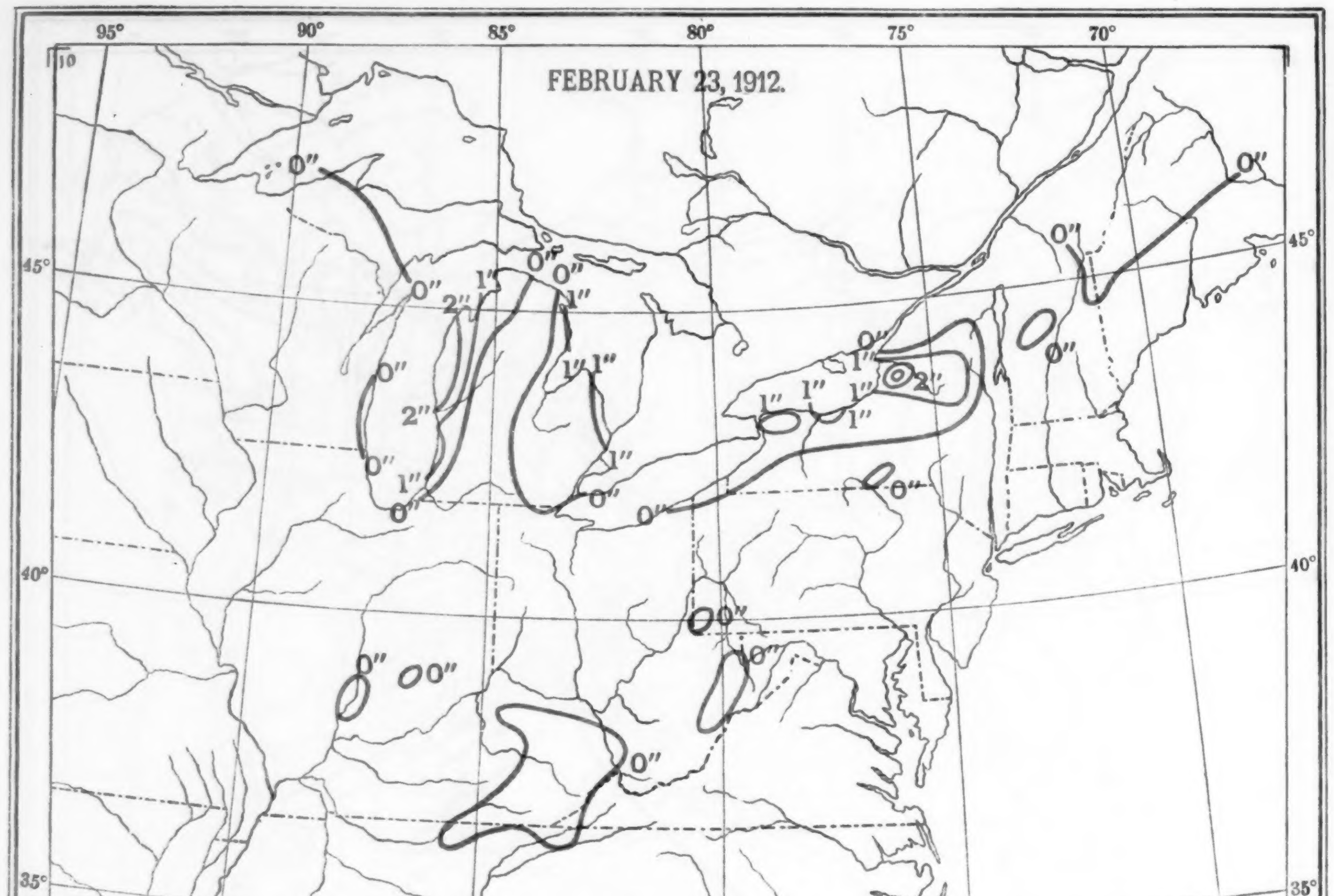

FIG. 10.—Snowfall over the eastern United States from sunset on February 22 to sunset on February 23, 1912. The fall over Lakes Huron and Michigan shows the advance of another cyclone. (Depths in inches.)

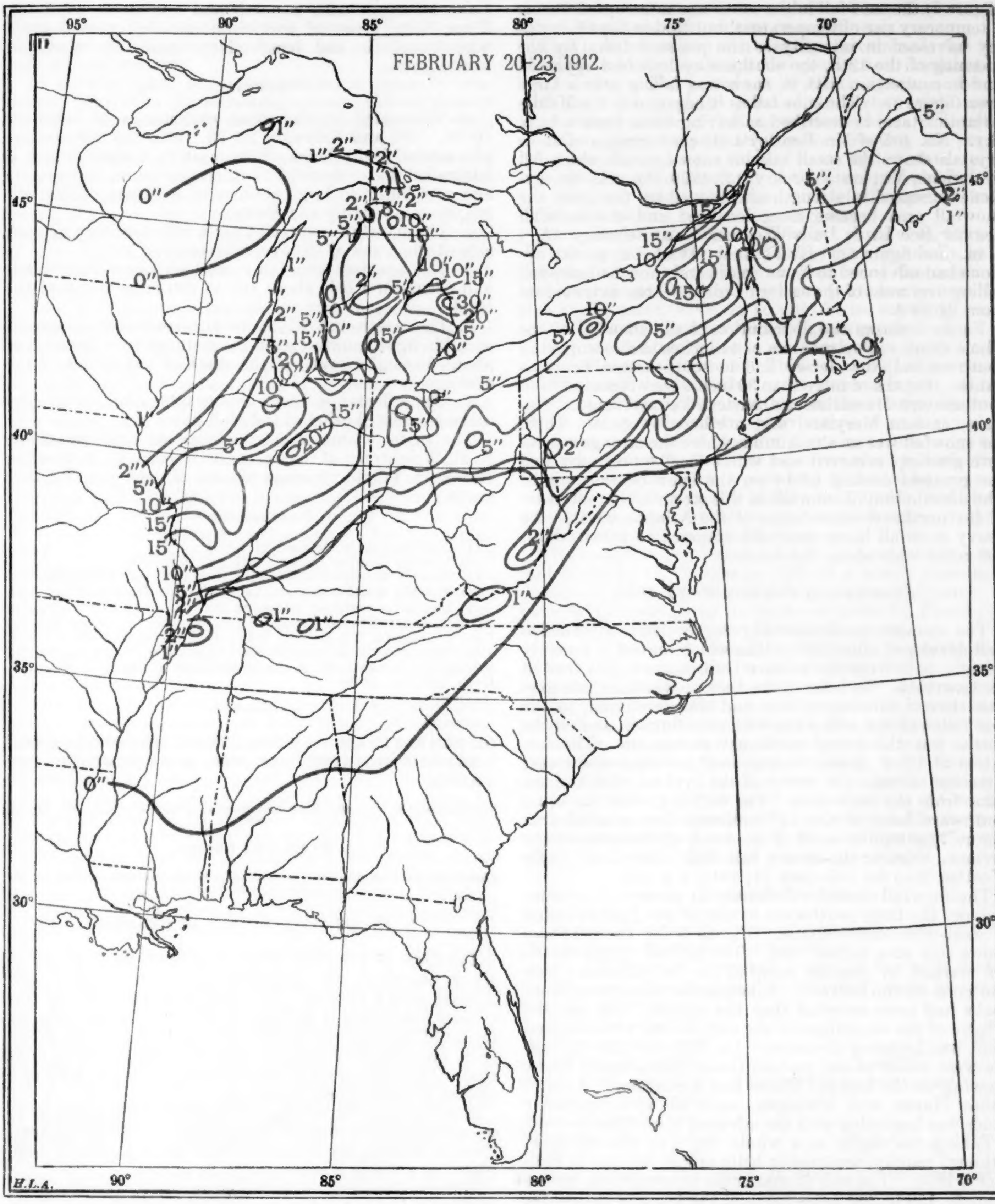

FIG. 11.—Total snowfall over the eastern United States for the storm of February 19-23, 1912. The belt of maximum fall is 150-200 miles north of the track of the Low center (Depths in inches.)

(figure 2) the snowfall in the south was interrupted during a temporary rise of temperature, but that in the Ohio valley increased in intensity as the pressure fell. By the morning of the 12th, the southern cyclone had appeared and in connection with it, snow was falling over a large area (figure 3). The snowfall as it began over the Middle Atlantic States is described as having come from a hazy sky. No. 405 of Mr. Bentley's (4) photographs of snow crystals shows the small tabular snow-crystals which fell in Jericho, Vt., on February 13, 1899 (5). As the cyclone increased in strength and moved up the coast the snowfall area became more localized and the snowfall heavier (see U. S. Daily Weather Map, February 13, 8 a. m., and figure 4). By February 14 at 8 a. m. the cyclone had advanced to Nova Scotia and snow had stopped falling over most of the eastern United States, as is evident from figure 5.

Figure 6 shows the distribution of the snowfall of the whole storm. Two maxima of 44 inches each occurred in south-central New Jersey and in southeastern Pennsylvania. Depths of more than 30 inches were reported from southeastern Massachusetts, eastern Pennsylvania, Delaware, eastern Maryland and northern Virginia. Thus, the snowfall was at a maximum where the strongest pressure gradient occurred and where local topography had the greatest cooling effect on the snow-bearing winds. The distribution of snowfall in this storm is characteristic of the northeast snowstorms of the Atlantic coast,—the heavy snowfall being generally confined to a belt about 200 miles wide along the coast.

Snowstorm of February 20–23, 1912.

The snowstorm of February 20–23, 1912, attended a well-developed elliptical cyclone which moved in a nearly straight path from the western Gulf States to the Gulf of St. Lawrence. In front of the cyclone was the characteristic sirocco with heavy rain and thunderstorms; in the rear followed the cold-wave with snowflurries, and on the north, was the heavy northeast snowstorm. The isotherm of 32° F. passed in a general northeast-southwest direction through the center of the cyclone, dividing the rain- from the snow-area. Far in front, with the usual southward bend of the 32° isotherm, the snowfall area (figure 7) extended south of the track of the center of the cyclone. Nearer the center, rain fell. (See U. S. Daily Weather Map for February 21, 1912, 8 a. m.)

The snowfall chart for February 21 presented in figure 8 shows the large southward extent of the light snowfall of west-wind snow-flurries. Figure 9 for the next day shows this area farther east. The central Appalachians are marked by heavier snowfall on the windward side and none on the leeward. Likewise the western Adirondacks had more snowfall than the eastern: this was the reverse of the conditions of the day before, when an east wind was bringing the snow. On February 23 (fig. 10) the west winds of the eastern Great Lakes made heavy snowfall on the leeward shores and mountains. Around Lakes Huron and Michigan, snowfall with southerly winds was beginning with the advance of another cyclone.

Taking the storm as a whole (fig. 11), the snowfall, although patchy, occurred in belts as was the case in February, 1899. The belt of maximum snowfall was, on the average, 150 to 200 miles north of the track of the center of the cyclone. In this belt the heaviest snowfall, 30 inches, occurred on the west shore of Lake Huron, most of it falling on the 21st with the easterly gale. The next heaviest snow, 24 inches, fell on the southeast shore of Lake Michigan with a north and northwest wind (6). Thus, both areas of maximum snowfall were located where cyclonic and local effects made the strongest combination.

SUMMARY.

As illustrated by the great snowstorms of February 10–14, 1899 and February 20–23, 1912, the distribution of snowfall in cyclones of the eastern United States is controlled by cyclonic action, temperature, topography and proximity to large sources of moisture. This distribution is roughly as follows:

1. The snowfall is spread over a wide territory on each side of the track of the cyclonic center.
2. The heaviest snowfall comes with northeast winds and occurs in a belt about 100 to 200 miles north of the track.
3. The northwest winds in the southwest quadrant sprinkle light snowfall over the country to a distance of about 300 miles south of the track of the center of the cyclone.
4. The effects of local topography and geography make the distribution of snowfall patchy.

The writer wishes to acknowledge the courtesy of Mr. R. H. Weightman of the Forecast Division, U. S. Weather Bureau, in sending tracings of some of the 8 p. m. weather maps.

REFERENCES.

(1) Contributions to Meteorology, 1882.
(2) Monthly Weather Review, 1911, pp. 1609–1616.
(3) Monthly Weather Review, May 1901; do., Ann. Sum. 1902.
(4) Monthly Weather Review, Ann. Sum. 1902, Plate II (XXX–119).
(5) Detailed accounts of this storm and its human effects are given in the Monthly Weather Review, February 1899, and in the Weather Bureau Climate & Crop Reports, February 1899, for the different States.
(6) For a study of snowstorms with reference to wind direction and cyclonic action see A. B. Crane, Snowstorms at Chicago. Am. Met. Journ. 1892, pp. 63–66.

ON THE INFLUENCE OF THE DEVIATING FORCE OF THE EARTH'S ROTATION ON THE MOVEMENT OF THE AIR.(1)

[Communicated to the International Meteorological Congress at Chicago, Ill., August, 1893.][1]

By DR. NILS EKHOLM.

(Dated Statens Meteorologiska Centralanstalt, Stockholm, 1893. Revised by the author, June, 1914.)

I. ON RELATIVE MOTION IN GENERAL.

Let there be a system of material particles or points at which observers are stationed; the earth's surface constitutes such a system. An observer at one point of this system can detect a motion of the other points only by means of the changes in their mutual distances and directions and will thus conclude that the whole system is at rest. This perception of motion among the particles of a system is called relative motion.

Now suppose the whole system of material particles to include not only the earth but also the whole solar system; then all motions are considered as relative to this system, which as a whole is supposed to be at rest.

If the system include the whole universe, then the latter must necessarily be considered as at rest. Since we have no more general system of points, therefore, motion relative to the universe as a whole is the most general of which

[1] See MONTHLY WEATHER REVIEW, February, 1914, 42: 93.

we are able to conceive and may be called *absolute motion*. More strictly speaking, absolute motion may be defined as motion relative to a system at rest, but such a motion is only an imagination.

In meteorological researches motion is generally considered relative to the terrestrial system, and our present purpose will be to determine the general laws of such motion.

The movement of a material system consists either of a translation or a rotation, or of both simultaneously. Translation takes place if the straight line joining any two points of the system always remains of the same length and parallel to itself; or, in other words, when all points of the system have simultaneously equal and parallel velocities and accelerations, although they may vary with the time.

Now, with respect to translatory motion, we know from experience that the relative motion of the points in a system is quite independent of any motion of the system as a whole. Thus, an observer at any point in the system, unless he has a motionless point of reference outside the system, will be unable to detect the motion of the system as a whole; but, on the other hand, he will not need to know this latter motion in order to determine the laws of relative motion within the system.

This is not true of rotatory motion, which is of such a character that a straight line joining any two points of the system is in general continually changing its direction. Now, suppose all these connecting lines to be of constant length, then the system will be in relative rest, but the laws of motion of a point moving relative to the system will be essentially different from those for a nonrotating system. In fact, we will soon prove that in a rotating system the relative motions within the system will be governed not only by the *true* or *absolute accelerations*, or *forces*, but also by two apparent forces produced by the rotation of the system.

Generally, the motion of a system is *simultaneously* both rotatory and translatory; but in all theoretical researches, in accordance with a well-known mechanical principle, we may suppose these two species of motion to take place successively and independently. For instance, we may suppose, first, that in any system the point M moves to its final position M' by means of translation only; and, second, that all other points of the system are brought to their final positions by rotating the whole system about M'. Also, since any translatory motion of the system does not influence the relative motions within it, we may, for the sake of simplifying the study of relative motions, imagine the system brought to rest by giving it a translatory motion equal and opposite to the actual translatory motion.

With respect to rotatory motion, however, it may be that there always exists in a rotating system a series of points located on one and the same straight line that remains in the same position for at least an instant, thus forming an *instantaneous axis of rotation*. Generally, this axis is changing its position and direction with time, relative to both absolute space and the rotating system. As to the terrestrial system, however, the change in the direction of the instantaneous axis of rotation is so extremely slow that its influence on relative motion within the terrestrial system may be neglected; also, the rotatory or angular velocity of this system is constant; and thus our investigations are very much simplified.

In investigating the laws of motion of a particle we have to deal chiefly with its *velocity* and *acceleration* of motion, both of which are determined at any moment by their respective magnitudes and directions, the latter of which may be either positive or negative.

The laws of velocity are easily determined, for the absolute velocity is always the geometrical resultant of the velocity of the particle in its relative path combined with the velocity of the point of the system with which the moving particle at that moment coincides. The proof of this is given immediately by constructing the parallelogram of velocities. Similarly, we find that the relative velocity is the resultant of the absolute velocity and the reversed velocity of the point of the system with which the moving particle is coincident.

As to the earth's motion, different parts of it, that is, different points in the terrestrial system, generally have different absolute velocities on account of the rotation; and accordingly we conclude that a particle moving relative to the earth, since on account of its inertia it tends to maintain its absolute velocity, must generally tend to change its relative velocity with reference both to its magnitude and direction. This reasoning, if correctly followed, will lead to the exact determination of the influence of the earth's rotation on the relative motions of the air. On the contrary, by means of an incomplete but very common deduction that considers only the changes of magnitude of the relative velocity, neglecting the changes of direction, we are lead to the old but inexact explanation first given by Hadley in 1735 (**2**), and afterwards reproduced by Dove and several other modern writers, especially in popular treatises.

The complete and exact solution of this problem was first given by G. Coriolis in 1835 as a purely analytical deduction (**3**); but the first extended application of Coriolis' theorem to air motions was made by Ferrel (**4**), and later by Guldberg and Mohn and others.

Ferrel's deduction, like that of Coriolis, is purely analytical, and, as it seems, is an independent one. Guldberg and Mohn (**5**) as well as several other later meteorologists, merely cite the required theorems as known from treatises on theoretical dynamics. The purely analytical deduction, although it is exact and general, is not so perspicuous as a geometrical demonstration, and I therefore think it may be well to give here a perfectly rigid and general, and very simple proof of the theorem of Coriolis, probably due to Delaunay (**6**), and so much the more as several elementary proofs, e. g. those of Sprung (**7**), and others, are neither rigid and general, nor simple.

II. CORIOLIS' THEOREM.

Lemma. The acceleration of a mobile mass may be geometrically determined as follows:

Let AB, figure 1, represent a part of the path that a mobile mass describes in the infinitely short space of time dt, and v its velocity at the point A. If there were no acceleration the mobile mass would, in the time dt, describe the path $AC = vdt$, AC being tangent to AB at A. In order that it may come to the point B, there is also required a component of motion, CB, and to produce this a constant acceleration, $\frac{2CB}{dt^2}$, must act during the time dt. Now, dt being infinitely small, the acceleration during this time is necessarily constant.

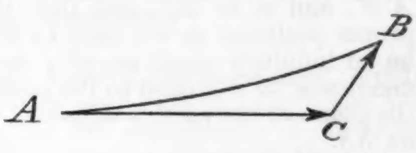

Fig. 1.

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Coriolis' theorem.—Now let AB, fig. 2, represent the absolute position in space at the time t, of the path of a mobile M, which we will suppose to be a particle of air

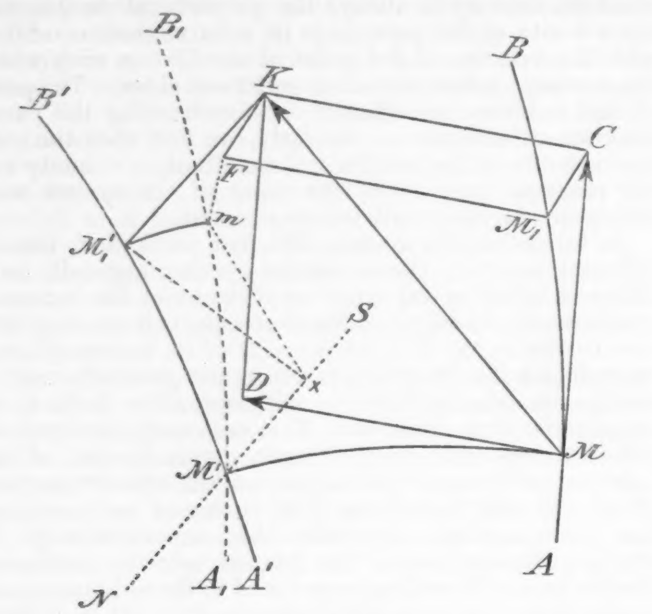

Fig. 2.

moving in the terrestrial system (8); $A'B'$ its position at the time $t+dt$; MM' the position of the path of M relative to a fixed point in the terrestrial system; hence MM' is an infinitely small part of a parallel of latitude on the earth. The point M of the terrestrial system will, by the earth's rotation at the time $t+dt$, be carried to M', and, similarly, the whole path AB will have been transferred to $A'B'$. Now, let v represent the absolute, and v_r the relative velocity of the mobile M at the time t, and v_s the velocity of that point in the terrestrial system with which M coincides at this time. By taking the points M_1 and M_1' in AB and $A'B'$, so that

$$MM_1' = M'M_1' = v_r dt,$$

then M_1' will be the actual position of the mobile at the time $t+dt$, and MM_1' the absolute path during the time dt.

But, according to the principle stated in Section 1, we may suppose the absolute motion from M to M_1' performed as follows: First, let the earth receive a translatory motion, so as to carry AB to A_1B_1, then M to M', and M_1 to m. It follows that $M'm$ is equal and parallel to $MM_1 = v_r dt$. Then let the earth rotate about the axis $NM'S$, parallel to the earth's axis (in the figure N is directed northward); therefore A_1B_1 will be carried to $A'B'$, and m to M_1', and thus they will come to their proper positions at the time $t+dt$. The path mM_1' will be an infinitely small arc of a circle whose plane is perpendicular to NS (also to the earth's axis, and parallel to the plane of the earth's equator), and whose center, x, is on NS.

Let ω represent the angular velocity of the earth, and γ ($=mM'S$ or $M_1'M'S$) be the angular inclination of the path of the mobile to the earth's axis at the time t; then the angle of rotation, $m \times M_1'$ will be ωdt, and the radius mx will equal $v_r dt \sin\gamma$. Hence, the arc $mM_1' = \omega v_r \sin \gamma dt^2$, or if for the sake of abbreviation we put

$$\varphi_\omega = 2\omega v_r \sin\gamma, \tag{1}$$

we will have

$$\varphi_\omega = \frac{2mM_1'}{dt^2}.$$

Let us draw at M tangents to the curves AB and MM', and on these take the lengths $MC = v_r dt$, and $MD = v_s dt$, and complete the parallelogram $MCKD$; then the direction of the diagonal MK coincides with that of the absolute velocity v, and the length $MK = vdt$ is equal. Now, according to the lemma, the absolute acceleration which we will represent by φ is equal to $\frac{2KM_1'}{dt^2}$.

Also, since KF is equal and parallel to CM_1, the relative acceleration may be represented by $\varphi_r = \frac{2KF}{dt^2}$, and finally, Fm being equal and parallel to DM', since M_1F and M_1m are equal and parallel to MD and MM', respectively, the acceleration of the point in the terrestrial system may be represented by

$$\varphi_s = \frac{2DM'}{dt^2} = \frac{2Fm}{dt^2} \tag{2}$$

Now, according to the well-known theorem of the composition of forces or velocities, we see by inspection of the skew=skew quadrilateral $KFmM_1'$ [that is, a quadrilateral whose sides are not in one plane], that KM_1' is the geometrical resultant of KF, Fm, and mM_1'. Since the same reasoning applies to any quadrilateral similar to $KFmM_1'$ and similarly situated, and calling to mind the mechanical significance deduced above for the sides φ, φ_r, φ_s, and φ_ω, which are $\frac{2}{dt^2}$ times the sides of the above quadrilateral, we have

$$\varphi = \text{geometrical resultant of } \varphi_r, \varphi_s, \text{ and } \varphi_\omega; \tag{3}$$

that is, the absolute acceleration φ is the geometrica resultant of the relative acceleration φ_r, the acceleration φ_s, of the point on the terrestrial system, and the acceleration, φ_ω, defined by equation (1). This is Coriolis' theorem, the meaning of which will now be more closely examined.

The component of acceleration, φ_ω, is called by Despérioux *complementary acceleration* (accélération complementaire); Coriolis himself less conveniently calls it the *composed centripetal acceleration* (accélération centripète composée) and calls the acceleration in the opposite direction, of which we will soon speak, the *composed centrifugal acceleration* (accélération centrifuge composée). According to equation (1) the magnitude of the complementary acceleration, φ_ω, is equal to twice the product of the angular velocity of the earth, ω, into the projection of the relative velocity upon the equator plane ($= v_r \sin\gamma$); and by inspection of figure 2 we find that since the direction of φ_ω, including its sign, plus or minus, coincides with mM', it is perpendicular to the relative path as well as to the axis of rotation, and acts in the same direction and with the same sign as the rotation. If there is no rotation ($\omega = 0$), φ_ω will vanish, as in fact we know it must, since the motion is then a translatory one.

On account of the simple rotatory motion of the earth we may easily deduce a general and simple expression for the acceleration, φ_s, of the point on the terrestrial system. Its direction and sign coincide with DM', figure 2, and its magnitude is given by equation (2). We see from figure 2 that DM' is parallel to the equator plane and, as dt is infinitely small, it is also perpendicular to the path MM' and thus is directed inward toward the earth's axis.

Let us redraw this part of the figure in figure 3. Let $M'L$ be tangent to MM' at M'. Since the arc $MM' = v_s dt$, is a part of a parallel circle of radius r_1, we shall have

$$MM' = v_s dt = r_1 \omega \, dt;$$

from which we obtain, $v_s = r_1 \omega$.

Also the angle DLM' formed by the two tangents at M and M' is equal to ωdt; and since in the infinitely nar-

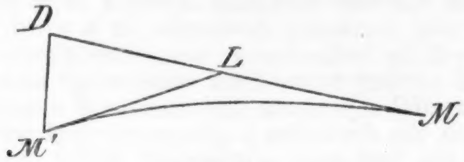

Fig. 3

row triangle DLM' the two angles at D and M' may be considered right angles and therefore equal

$$LD = LM' = LM = \tfrac{1}{2}v_s dt = \tfrac{1}{2}\omega r_1 dt;$$

also, the side DM' may be considered equal to the arc DM', the center of which is at L; consequently

$$DM' = DL\omega dt = \tfrac{1}{2}\omega^2 r_1 dt^2 = \tfrac{1}{2}\frac{v_s^2}{r_1}dt^2$$

and thus by equation (2)

$$\varphi_s = \omega^2 r_1 = \frac{v_s^2}{r_1}. \qquad (4)$$

Let λ be the geocentric latitude and r the corresponding radius (9) of the earth; then

$$r_1 = r \cos \lambda,$$

and thus finally

$$\varphi_s = \omega^2 r \cos \lambda = \frac{v_s^2}{r \cos \lambda}. \qquad (5)$$

φ_s is called the centripetal acceleration of the earth; it forces the parts of the earth to move in parallel circles around its axis instead of in straight lines in accordance with the law of inertia. The force required is taken from gravity, and therefore the remaining component of gravity, called *apparent gravity*, the only component that we are able to observe directly on the earth, is a little less than the *absolute gravity*, as that calculated by astronomers is called, and acts in a slightly different direction.

In order to conveniently apply the theorem of Coriolis to meteorological phenomena, we must reverse it, as a closer inspection of the above-named accelerations will show.

Among all these, the acceleration of the point in the terrestrial system, φ_s, is the one that may be *most easily and exactly* determined, since it depends only upon the dimensions and motion of the earth and upon the geographical position of the mobile, as is seen from equations (4) and (5). Next come the absolute accelerations φ, such as the absolute gravity, the gradients of atmospheric pressure, and friction. Generally these may either be calculated, or determined by experiment or observation. More difficult is the determination of the complementary acceleration φ_ω; it may be calculated, but only when the relative velocity v_r is known, as will be seen from equation (1); but v_r may be determined by observation. Finally, for the relative acceleration, φ_r, there is at present no method of experiment or observation to determine it, and no other method of calculating it than by means of Coriolis' theorem. Thus in all meteorological researches φ_r is to be regarded as unknown in equation (3), which must be solved with respect to it.

For this purpose let us draw in figure 4 the skew quadrilateral $ABCD$, whose sides, AB, AD, DC, and CB, are equal to and have the same direction as φ, φ_r, φ_s, and φ_ω, respectively;[2] this quadrilateral is therefore similar and similarly situated to $KFmM_1'$ in figure 2.

[2] In figure 4 the side BC has been lettered φ_w instead of φ_ω.—EDITOR.

By inspection AD is equal to the resultant of AB, BC, and CD, as regards magnitude, direction, and sign. Now, $AD = \varphi_r$, $AB = \varphi$, and BC and CD are φ_ω and φ_s *reversed.* Let the former be denoted by ψ, and the latter by ψ_s in respect to magnitude, direction, and sign; then

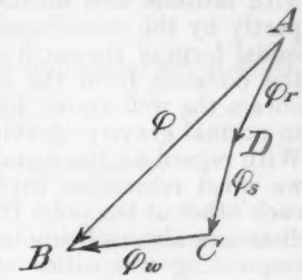

Fig. 4

See footnote.

$$\varphi_r = \text{resultant of } \varphi, \psi, \text{ and } \psi_s \quad (6)$$

This theorem, which is only another form of Coriolis' theorem, when referred to relative air motion, by putting force instead of acceleration proportional to the relative motion, and hereafter representing the relative velocity simply by v, may be expressed in words in the following manner:

The external impressed forces, φ_r, which accelerate an air particle have the following components:

1. *The absolute impressed forces, φ (absolute gravity, pressure gradients, and friction).*
2. *The centrifugal force of the earth, ψ_s, at the geographical point of the particle, ψ_s, being equal to $\omega^2 r \cos \lambda$, meeting the earth's axis perpendicularly, and acting outward.*
3. *The deviating force, ψ, which is equal to $2\omega v \sin \gamma$, is parallel to the equator plane and perpendicular to the path of the particle, and acts in a direction opposite to that of the earth's rotation.*

We call to mind that ω is the angular velocity of the earth and r the radius drawn from its center to the particle, λ the geocentric latitude of the particle, and γ the angular inclination of the path of the particle to the earth's axis.

The two forces ψ_s and ψ are called *apparent external impressed forces;* these having been introduced into the equations of dynamical meteorology, we may treat atmospheric motions according to the usual mechanical methods, quite as if the earth were at rest. The great advantage of this method of treatment is evident from the fact that the earth seems to our immediate perception to be at rest and consequently the air motions to be absolute motions. Therefore, since Coriolis' theorem affords a quite exact method of treating the meteorological phenomena according to our natural perception of them, it is of the highest importance to meteorological science. In fact, this method has already been generally accepted; but certainly in an incomplete manner, as several components of forces have been neglected at random without determining the errors thereby introduced.

III. APPLICATION OF CORIOLIS' THEOREM TO DYNAMIC METEOROLOGY.

First, the centrifugal force ψ_s may be very briefly treated, for as has already been said this force and the absolute gravity form the two components of *the apparent gravity.* Under the action of this force the earth's once fluid sphere has taken the form of an oblate spheroid whose surface, being at all points normal to the direction of apparent gravity, constitutes a level surface (surface de niveau). At the present time this applies directly only to the surface of the sea, although it also applies to the *ideal* sea surface drawn through the continents, which has been determined by a system of levels, and is the surface to which barometric observations are reduced. Thus the horizontal component of the centrifugal force is

accounted for. The vertical component is considered by taking into account the variations in apparent gravity with latitude and altitude, this variation being caused partly by the centrifugal force and partly by the spheroidal form of the earth and the consequent variation in the distance from the center with latitude. Thus we obtain the well-known formulas for reducing air pressure to normal gravity (gravity at lat. 45° and at sea level). With regard to the distance between two level surfaces, we must remember that two such surfaces are nearer each other at the poles than at the equator, their mutual distances always being inversely proportional to the corresponding intensities of apparent gravity (**10**). We need not here enter into the details of this question.

Second, as to the deflecting force

$$\psi = 2\omega v \sin \gamma; \tag{7}$$

its intensity and direction depend upon the position of the relative path and on the relative velocity, and it must always be treated as an external impressed force.

Let us first refer the motion to the earth's axis and the equator plane. Let figure 5 present a north-polar pro-

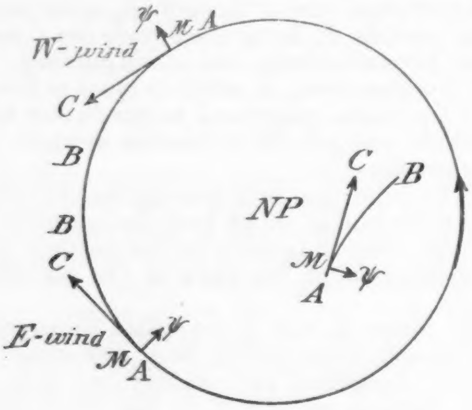

Fig. 5.

jection of our globe, AB the projection of the relative path, and $MC = v \sin \gamma$ that of the velocity, v, of the particle M. Then with respect to magnitude, $\psi = 2\omega\, MC$. If now we imagine an observer placed at M, parallel to the earth's axis and with his head towards the north pole (that is, perpendicularly upward in the figure), and looking toward C, he will see the earth rotate before him from his right to his left hand; and therefore ψ, which is directed in the opposite direction, will urge the particle toward his right hand and perpendicularly to MC in the equator plane, as drawn in the figure. In the Southern Hemisphere ψ acts similarly toward the left. If the path is parallel to the equator ($\gamma = 90°$), ψ will have its maximum value $2\omega v$, which is a constant for the whole earth. If the path is perpendicular to the equator ($\gamma = 0°$), ψ vanishes at all points on the earth.

Second, let us refer the motion to the zenith and the horizon.

As has just been shown, in the *neighborhood of the pole* in a *horizontal current*, ψ is always equal to $2\omega v$, is independent of the azimuth of the motion and is directed *horizontally* to the right at the north pole, and to the left at the south pole; there is no vertical deviation, and consequently *a vertical current is not deviated at all.*

In the *neighborhood of the equator in a north south horizontal current*, the path being perpendicular to the equator plane, *the deviation is zero;* but in an *east-west current* the path is parallel to this plane. Therefore $\psi = 2\omega v$, is directed vertically upward in a wind from the west and vertically downward in a wind from the east, as will be immediately seen from figure 5. If a horizontal current blows from some other azimuth, the projection MC represents the east-west component of v; and thus the deviation is always vertical and proportional to the east-west component, being directed upward in a west wind and downward in an east wind. Also, we find immediately that in a vertical upward current ψ is directed horizontally westward, and in a vertical downward current it is directed horizontally eastward, and that $\psi = 2\omega v$.

Now let us consider *the deviation at any latitude* λ.

1. Air current horizontal.

(a) If the current is directed poleward, as in figure 6*a*, ψ will be directed horizontally eastward, and the projection of v on the equator plane being $v \sin\lambda$, we obtain

$$\psi = 2\omega v \sin \lambda.$$

The same value is obtained if v is directed toward the equator, but ψ will be directed westward.

(b) If v is directed eastward (west wind, fig. 6*b*), ψ is in the meridian plane parallel to the equator and directed

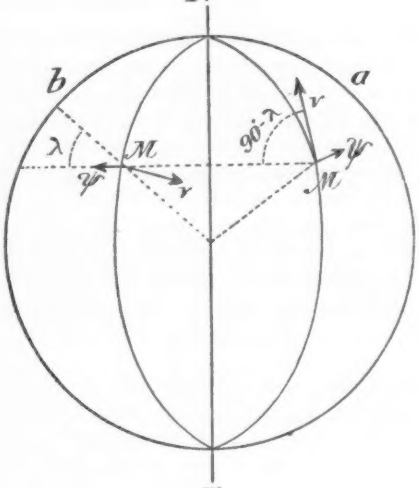

Fig. 6.

upward, thus forming, with the vertical, the angle λ; and v being parallel to the equator, we get

$$\psi = 2\omega v.$$

Thus the horizontal component of ψ, which we will call ψ_h, will be directed toward the equator, and we shall have for its magnitude

$$\psi_h = 2\omega v \sin \lambda;$$

the vertical component, which we will represent by ψ_z, will be directed upward toward the zenith, and we shall have for its magnitude

$$\psi_z = 2\omega v \cos \lambda.$$

If v is directed westward (east wind), we get the same values for ψ, ψ_h, and ψ_z, but the directions are reversed; ψ toward the earth's axis, ψ_h toward the pole, and ψ_z downward (toward the nadir).

(c) If v is directed in any azimuth, it may be resolved into two components, as presented in figure 7, the one, $v_x = MX$, with a north-south direction; the other,

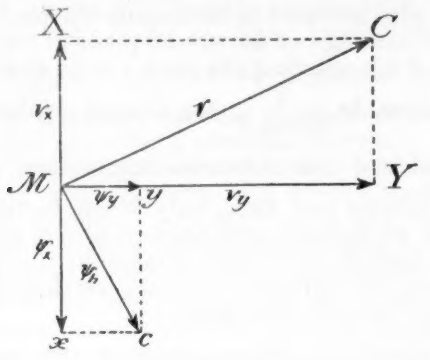

Fig. 7

$v_y = MY$, with an east-west direction. The effect of the component v_x will be, as shown in (a), to produce a component of deviation directed along MY, which may be expressed by the following equation:

$$M_y = \psi_y = 2\omega v_x \sin \lambda;$$

and the effect of the component v_y will be [as shown in (b)] to produce a horizontal component of deviation, which may be expressed by

$$M_x = \psi_x = 2\omega v_y \sin \lambda.$$

If the resultant of ψ_x and ψ_y is represented by ψ_h, this latter will be the horizontal component of the force of deviation. Now, by the above formulas,

$$\psi_y : \psi_x = v_x : v_y;$$

and since the right-angled triangles Myc and MXC are similar, therefore also $\psi_h : \psi_y = v : v_x$, and consequently

$$\psi_h = 2\omega v \sin \lambda. \tag{8}$$

Also, the angle CMc is right-angled, and it is immediately seen that ψ_h is directed to the right in the Northern Hemisphere (for which the figure is drawn), and to the left in the Southern Hemisphere. This is the theorem, already generally known, on the horizontal force of deviation in a horizontal air current.

Finally, we get also [from (b)] a vertical force

$$\psi_z = 2\omega v_y \cos \lambda, \tag{9}$$

directed upward in a westerly wind (v_y directed eastward), and downward in an easterly wind (v_y directed westward).

2. Air current vertical.

The projection of v on the equator being $v \cos \lambda$, the deviating force will be

$$\psi = 2\ \omega v \cos \lambda, \tag{10}$$

and it is immediately seen that it is horizontal and is directed westward in an upward, and eastward in a downward current.

3. Air current directed obliquely upward or downward.

This case may be easily reduced to the two former ones by resolving v into three components—the first, v_x, north-south; the second, v_y, east-west; and the third, v_z, vertical; taken positively to the north, east, and zenithward, respectively.

From v_x we get [by (*1.* a.)] only a horizontal east-west component of deviating force, which may be represented by the equation

$$\psi_y' = 2\ \omega v_x \sin \lambda;$$

from v_y [by case (*1.* b.)] we get a horizontal north-south force which may be expressed by

$$\psi_x = -2\ \omega v_y \sin \lambda,$$

and a vertical force that may be expressed by

$$\psi_z = 2\ \omega v_y \cos \lambda;$$

from v_z [by case *2*] we get only a horizontal east-west force which may be expressed by

$$\psi_y'' = -2\ \omega v_z \cos \lambda.$$

Thus we get the following components:

$$\psi_y' + \psi_y'' = \begin{cases} \psi_x = -2\ \omega v_y \sin \lambda; \\ \psi_y = \ \ 2\ \omega(v_x \sin \lambda - v_z \cos \lambda); \\ \psi_z = \ \ 2\ \omega v_y \cos \lambda. \end{cases} \tag{11}$$

Formula (11) represents, as may be easily seen, the components of the deviating force for either hemisphere as to magnitude, direction, and sign, if we make λ positive at a northern latitude and negative at a southern latitude.

Now let α be the azimuth from which the wind blows, counted from south through west; α will also represent the azimuth *towards which* the wind blows; that is, the azimuth of v counted from north through east. Let β be the inclination of the path of the wind to the horizon, a positive value of β corresponding to an upward wind, and a negative value to a downward wind. Then by projecting v on the axes we obtain

$$v_x = v \cos \alpha \cos \beta; \quad v_y = v \sin \alpha \cos \beta; \quad v_z = v \sin \beta;$$

and by putting these values of v_x, v_y, and v_z, in (11), we get

$$\begin{cases} \psi_x = -2\ \omega v \sin \alpha \cos \beta \sin \lambda; \\ \psi_y = \ \ 2\ \omega v(\cos \alpha \cos \beta \sin \lambda - \sin \beta \cos \lambda); \\ \psi_z = \ \ 2\ \omega v \sin \alpha \cos \beta \cos \lambda; \end{cases} \tag{12}$$

The complete discussion of formulas (11) and (12) being somewhat long, I will for this refer to my paper (**1**) and give here only the chief results.

In the Northern Hemisphere in an obliquely upward current *the horizontal component of the deviating force of a south wind is less, and that of a north wind is generally more, than in a horizontal current.* In an obliquely downward current the reverse holds good. As to the Southern Hemisphere, we need only to interchange the north and south in the above proposition. This symmetry of deviation is greatest near the equator. For instance, in the Northern Hemisphere, if the upward inclination β of a south wind is equal to the latitude λ, $\psi = 0$; (**11**) if $\beta > \lambda$, ψ will be directed to the left. The north and south winds are never vertically deviated.

If in an east-west current the air is obliquely rising or falling ψ_h will not be directed exactly perpendicular to v, but if the air is rising it throws the east winds a little forward and the west winds a little backward, and the reverse of this if the air is falling. The west winds are always deviated upward and the east winds downward.

IV. RELATIVE PATH OF INERTIA OF AN AIR PARTICLE.

If no external forces accelerate a mobile, it will, on account of its inertia, describe a straight line with a constant velocity; this is therefore the absolute path of inertia.

The path that the mobile under the same conditions will describe on a moving system, such as the earth, is however generally a curved line, on account of the two

apparent forces ψ_1 and ψ then brought into play, and it is described with varying velocity. But the simultaneous absolute path being a straight line and the absolute velocity constant, this relative path is also evidently a real path of inertia. Such a path would be described by a particle of air moving relative to the earth's surface, if the influence upon it of the absolute gravity, pressure-gradients, and friction, always balanced each other. Since the absolute path is a straight line, such a particle could never be at relative rest.

In meteorology there has, however, been introduced another definition of the path of inertia, which, while it does not well correspond to this name, may yet be of use in some investigations. Let us suppose that the influence of the *apparent* gravity, pressure-gradients, and friction, on the air particle, always balance each other. Under these conditions, if the air particle was at relative rest at the beginning it would remain at rest; and if at the beginning it had a certain relative velocity, due to some external impressed force, it would on account of its inertia maintain this velocity unaltered, and only change the direction of its relative path; for the only force acting upon it would be ψ, which has been shown to be always acting perpendicularly to the relative path. Such a path of inertia may consequently be called the *apparent path of inertia.*

1. First, let the original direction of the path be parallel to the earth's axis. Then $\psi=0$, and the relative path is a straight line parallel to the axis of the earth.

2. Second, let the original direction of the path be parallel to the equator plane, and the original velocity equal to v. Then the deviating force will be $\psi=2\omega v$, and also acting parallel to the equator plane. Since ψ is constant and perpendicular to v, the path will evidently be a circle whose radius, ρ, will be determined by putting the resistance of inertia of the particle, $\frac{v^2}{\rho}$, equal to ψ, thus:

$$\frac{v^2}{\rho}=2\omega v,$$

by which

$$\rho=\frac{v}{2\omega}.$$

The periphery being $2\pi\rho$, and v being the part of the periphery described in a second of mean solar time, the time of the whole revolution will be $\frac{2\pi\rho}{v}=\frac{\pi}{\omega}$ seconds of mean solar time; that is, one half of a siderial day (**12**). The radius is proportional to v, and if $v=1$ m./sec., $\rho=6\,857$ meters; if $v=10$ m./sec., $\rho=68\,570$ meters, etc. The direction of motion is opposite to that of the earth's rotation; at the pole the plane of the path is horizontal and at the equator it is vertical, the direction being eastward in the lower half of the path and westward in the upper half. At any latitude the plane of the path, which is always parallel to the plane of the equator, will be inclined to the horizon, the direction of motion being the same as at the equator.

3. Third, let the original direction of motion be inclined by an angle γ to the earth's axis. Then let v be resolved into two components, $v \cos \gamma$ and $v \sin \gamma$, parallel respectively to the earth's axis and to the equator plane. The effect of the first component alone will be to cause the particle to describe (by 1 above) a straight line parallel to the earth's axis, with the constant velocity $v \cos \gamma$; the effect of the second component taken alone will be (by 2 above) to cause the particle to describe a circle parallel to the equator plane and having the radius $\frac{v \sin \gamma}{2\omega}$. The actual path will therefore be a helix, having its axis parallel to the earth's axis.

We may also attempt to determine the path of inertia of a particle moving in a horizontal plane at the latitude λ. Here, also, if λ is constant the path will be a circle having the radius equal to $\frac{v}{2\omega \sin \lambda}$; the time of revolution will be $\frac{\pi}{\omega \sin \lambda}$; that is, $\frac{1}{2}$ cosec λ times a siderial day (**13**). Such a path of inertia can exist only when certain vertical forces, such as pressure and temperature gradients, constrain the particle to always remain in the same horizontal plane; for instance, when the vertical equilibrium of the atmosphere is very stable.

V. COMPARISON BETWEEN THE THEORY AND EXPERIENCE.

Thus far our deductions have been purely theoretical, and the results given above possess mathematical certainty; but whether the apparent forces generated by the earth's rotation are essentially important to dynamic meteorology depends upon the order of magnitude of these forces. They will be of importance only when they are of the same order of magnitude as the absolute forces, pressure gradients, and friction, which we know from observation produce and stop air motion. This question will now be examined.

In comparing these forces we shall express all in the centimeter-gram-second system.

The *unit of force*, the dyne or $\frac{\text{g. cm}}{\text{sec}^2}$, is the force which acting during one second (sec.), mean time, on a mass of one gram (g.) produces an acceleration of one centimeter (cm.). Thus pressure is measured in dynes per square centimeter $\left(\frac{\text{dyne}}{\text{cm}^2}=\frac{\text{g}}{\text{cm.sec}^2}\right)$

A normal atmosphere (measured by a column of mercury 76 cm. in height *reduced to* normal density and gravity) is equal to $1.01325\times10^6 \frac{\text{dynes}}{\text{cm}^2}$ and thus very nearly a million dynes or one megadyne per cm^2.

In a horizontal air current the only moving force is the horizontal gradient $-dp/dx$, that is, the diminution of pressure per unit of length along a level surface, or a surface at all points normal to apparent gravity. Let G be this gradient in centimeters of mercury for 1° along the meridian, dp the diminution of pressure in dynes/cm^2 and dx the corresponding variation of length expressed in centimeters; we will then obtain

$$-\frac{dp}{dx}=\frac{1.01325\times10^6}{76}\cdot\frac{90}{10^9}\cdot G, \text{ in } \frac{\text{dynes}}{\text{cm}^3};$$

that is,

$$-\frac{dp}{dx}=0.001200G, \text{ in } \frac{\text{g}}{\text{cm}^2.\text{sec}^2}. \tag{13}$$

This equation represents the variations in the pressure acting on 1 cubic centimeter of air moving in a horizontal path. In order to obtain the acceleration in cm./sec.^{2}, it must be divided by the mass of a cubic centimeter of air; that is, by the density of the air, δ, in $\frac{\text{g}}{\text{cm}^3}$; we thus obtain for the acceleration produced by the gradient G,

$$-\frac{1}{\delta}\frac{dp}{dx}=\frac{0.001200}{\delta}G, \text{ in } \frac{\text{cm}}{\text{sec}^2}. \tag{14}$$

For example, let the air have a temperature of 17.0°C., a pressure of 75.3 cm., and a relative humidity of 70 per cent, a condition that nearly corresponds to the summer mean of northern Europe; then $\delta=0.001200$, and the acceleration sought will be simply equal to G.

We thus see that at the mean air density, $\delta=0.001200\frac{g}{cm^3}$, the acceleration produced by G will be expressed by the same measure of length as the gradient itself, if this is given for a meridian degree.

Now we know by observation the relation between gradient and wind velocity in a steady motion. In a cyclone, for example, a gradient of 5 mm. (=0.5 cm.) will generally produce stormy winds with a velocity of about 30 meters per second (v=3 000 cm./sec.²). Then, since $\omega=0.00\,007\,292$, we get by equation (7) for a current parallel to the equator $\psi=0.44$ cm./sec.², which is nearly the same value as that for the acceleration produced by the gradient, this latter being 0.5 cm./sec.². Further, since, as we know, the horizontal deviation of the wind from the direction of the gradient amounts to at least 60°–70°, only G cos 60° to G cos 70° or about $\frac{1}{2}$ to $\frac{1}{3}$ of the gradient force will accelerate the air movement, while the remaining component, G sin 60° to G sin 70°, or about $\frac{7}{8}$ to $\frac{16}{17}$ of G, being perpendicular to the path, will unite with the horizontal component of ψ [or $\psi_h=2\omega\, v \sin\lambda$ by equation (8)] in a resultant perpendicular to the path and tending to incurve it, thereby modifying the distribution of the mass and the pressure of the air.

The vertical component of ψ [or $\psi_z=2\omega v_y \cos\lambda$ by equation (9) or (11)] will also tend to incurve the path, the direction being upward in a west wind (v_y positive), and downward in an east wind (v_y negative), and thereby likewise modify the distribution of the mass and the pressure of the air. This component has hitherto been very generally neglected, but as will be seen below, this will not do.

Further, as the researches of Guldberg and Mohn (**14**) have shown, the resistance of friction caused by the earth's surface on the lowest strata of the atmosphere, like ψ, is a quantity proportional to v; friction $=kv$.

The coefficient of friction, k, ranges between 0.00002 and 0.00004 for the open sea, and does not exceed 0.00012 for a very rough continental surface. Friction even at its maximum will therefore be less than ψ, or $2\omega v$, in a current parallel to the equator ($2\omega=0.00\,014\,584$).

As to the upper strata of the atmosphere H. von Helmholtz (**15**) has shown the friction in a horizontal parallel current is so extremely small that it vanishes altogether when compared with the gradient. Hence it follows that in the upper strata even a very slight gradient—for example, 0.1 mm. (0.01 cm.)—if it act sufficiently long in the direction of motion, is able to produce a very great velocity, particularly as the acceleration is inversely proportional to the density of the air. For instance, at an altitude where the density is only ⅓ of that at sea level (about 8 km., which corresponds to the average height of the cirrus), the acceleration produced by the above-named slight gradient will be 0.03 cm./sec.². This acceleration acting in the direction of motion during 100 000 seconds, or about 28 hours, will produce a velocity of 3 000 cm./sec. = 30 m./sec.; and with this velocity ψ is, as previously shown, equal to 0.44 cm./sec.², which is about 15 times greater than the component of acceleration acting in the direction of motion.

In order more fully to examine the action of the deviating force ψ, we must decompose it by means of the formulas given in Part III. If the air current is nearly horizontal, formulas (8) and (9) will suffice. Since the horizontal component is $\psi_h=2\omega v \sin\lambda$ and the vertical component is $\psi_z=2\omega v_y \cos\lambda$, the former will attain its greatest importance in the higher latitudes, and the latter in the lower latitudes.

The importance of ψ_h has already been shown by several eminent investigators, especially Ferrel, Guldberg and Mohn, Köppen, Sprung, De Marchi, and von Bezold; and having thus been generally acknowledged, we need scarcely discuss this part of the problem. The following remarks may suffice. Even in the vicinity of the equator, where this component nearly vanishes, it is essential to the formation of the trade winds and monsoons. This fact at once indicates that the vertical component ψ_z, even in the higher latitudes where it is comparable with the ψ_h of the lower latitudes, must have an essential influence on air movements. To be sure, there exists a great difference between the horizontal and vertical movements of the air, inasmuch as the former may amount to hundreds of miles, while the latter can only amount to a few miles; it therefore follows that, the accelerations and the other conditions of motion being equal, the horizontal velocities must be much greater than the vertical, since the time during which the accelerating forces act will be much greater in the former case. Nevertheless, no one will deny that a vertical displacement of the air masses for a few miles may not have as much influence on the weather as a horizontal displacement of many hundreds of miles. And even where such vertical forces do not directly produce motion, they will, since the conditions of continuity of moving air have always to be satisfied, call forth opposite forces, such as vertical pressure gradients or frictional resistances, which will essentially modify the conditions of equilibrium or motion of the atmosphere.

Some concrete instances of the magnitude and direction of the deviating force ψ in the upper currents of the atmosphere are here presented from the results of the cloud measurements executed by Dr. K. L. Hagstrom and myself in Upsala (**16**) (lat. 59° 51.5′).

Let z_m be the mean height of the cloud, v_h its horizontal velocity, and α_ψ the azimuth of ψ, the other symbols being those used in the formulas given in Part III.

1885, May 26, 8 p. m. Barometric depression to the north of Upsala. Five successive measurements of a cirrus cloud.

$$z_m=8\,068\text{ m.};\ \alpha=101.1;\ v_h=15.4\text{ m./sec.};\ v_z=2.2\text{ m./sec.};$$
$$\beta=8.1°;\ \psi_h=0.20\text{ cm./sec.}^2;\ \alpha_\psi=191.9°;$$
$$\psi_z=0.11\text{ cm./sec.}^2\text{ upward.}$$

1885, May 30, 8 a. m., depression to the north of Upsala. Six successive measurements of a cirrus cloud.

$$z_m=7\,405\text{ m.};\ \alpha=55.7°;\ v_h=42.0\text{ m.};\ v_z=2.6\text{ m.};$$
$$\beta=3.6°;\ \psi_h=0.52\text{ cm./sec.}^2,\ \alpha_\psi=147.4°;$$
$$\psi_z=0.25\text{ cm./sec.}^2\text{ upward.}$$

1885, June 6, 1 p. m., depression to the north of Upsala. Three successive measurements of a high cirrus cloud.

$$z_m=9\,143\text{ m.};\ \alpha=65.7°;\ v_h=43.8\text{ m.};\ v_z=6.3\text{ m.};$$
$$\beta=8.1°;\ \psi_h=0.54\text{ cm./sec.}^2;\ \alpha_\psi=160.2°;$$
$$\psi_z=0.29\text{ cm./sec.}^2\text{ upward.}$$

With regard to the density of the air at this height, we find that for the last two measurements ψ_h is equivalent to a horizontal gradient of about 2 mm., ψ_z to an upward vertical gradient of about 1 mm., using the ordinary units.

In order to judge exactly of the influence of the vertical deviating component, ψ_z, we ought to compare it with the vertical pressure gradients. The calculation and measurements of these latter are, however, much more difficult than the calculation and measurement of the horizontal pressure gradients.

If the air is at rest we know by the principle of Archimedes that the lift by air pressure is equal to the apparent weight of a unit volume of air; thus according to the adopted designation, g being the acceleration of apparent gravity,

$$-\frac{dp}{dz}=g\delta, \text{ or } -\frac{dp}{dz}-g\delta=0.$$

If, however, these two forces are unequal, the difference will represent the vertical moving force of pressure, or the vertical pressure gradient, $-\frac{dp}{dz}-g\delta$, the acceleration of which is $-\frac{1}{\delta}\frac{dp}{dz}-g$, and ought to be compared with ψ_z.

If the vertical height z is taken positively upwards, p will decrease when z increases, and thus $-\frac{dp}{dz}$ will be a positive quantity, representing an upward pressure. Putting

$$-\frac{dp}{dz}-g\delta=\varepsilon\delta \tag{15}$$

the gradient $\varepsilon\delta$ is directed upward when positive and downward when negative. Thus ε represents the acceleration imparted by the gradient to the unit of volume of air at the height z.

The only means of determining this gradient by observation is given by the barometric measurement of heights. In fact, if in equation (15) we put $\varepsilon=0$ and integrate the equation, we obtain the barometric formula for measuring heights. The uncertainty of such a measurement, however, is not due alone or principally to placing $\varepsilon=0$, for, as the discussion of the barometric formula shows, we are unable to determine with sufficient accuracy the air pressure, and especially the mean air density, which is a function of the temperature and moisture, and even of the dust and water particles floating in the air, for every element of the column lying between the two barometers to be read at its top and bottom (**17**).

In the general case, ε will vary from one element to another, and in order to determine the dynamical state of the atmosphere, we must write down and solve the general hydrodynamic equations, with due regard to all pressure gradients, friction, deviating force ψ, condition of continuity, and limits. This seeming at present impossible, we must confine ourselves to the study of some simple and typical phenomena, comparing them with the observed facts.

In doing this, let us first consider the vertical component of the inflowing air current of a steady cyclone. First, as shown by Hann and others, the rising mass of air in the inflowing current of such a cyclone is very nearly in the *adiabatic or indifferent* equilibrium.

Let us first suppose such a mass of air to be at rest. Then we have

$$-\frac{dp}{dz}=g\delta.$$

If now a particle of air be thrown upward, by means of an impact for instance, both the lifting power $-\frac{dp}{dz}$ and the weight $g\delta$ of the unit of volume of air will decrease. But since the surrounding mass of air is in adiabatic equilibrium, $-\frac{dp}{dz}$ and $g\delta$ will always decrease at the same rate. For since the moving air mass has not time to give out or receive a sensible quantity of heat, its change of state will be adiabatic; consequently, during its motion it will always take the same density as the surrounding air in the same level. Thus, the vertical gradient will remain zero, and the only forces acting upon the moving air particle will be the deviating force ψ and the friction. But the latter may be neglected on account of its smallness; hence the air particle, under the influence of ψ, will perform the apparent path of inertia described in Part IV. It must be remembered, however, that if the air is saturated with moisture but not charged with fog, the adiabatic equilibrium, and consequently the path of inertia, will exist in an upward motion only, while the stable equilibrium, which will be spoken of below, will manifest itself in a downward movement.

In reality the air column of a cyclone is not in equilibrium, but is rising under the influence of a vertical upward force, which is the resultant chiefly of the vertical pressure gradient and the vertical component ψ_z; also, its different strata are rotating around a vertical axis. That the acceleration of these vertical pressure gradients will probably in most cases be smaller than ψ, and even than ψ_z, especially in the upper strata, is shown by the following reasoning. The vertical pressure gradients must generally be smaller than the horizontal ones, because the frictional resistance is less, and the flow less checked than in a horizontal current. Now since the horizontal pressure gradients are generally not greater than ψ, or even ψ_h, the vertical gradients will be less than ψ, and not greater than ψ_z.

The above results of cloud measurements confirm this conclusion. In fact, it may be shown that in those cases the mean value of ε is probably negative, and therefore directed downward, and tending to move the air in that direction. To prove this, we must compute the upward velocity, v_z, that would be produced by the action of ψ_z alone, and compare it with the observed value of v_z. Now, ψ_z is proportional to the westerly component of velocity, v_y, and this, as shown both by our own cloud measurements and those of H. H. Clayton, is very nearly proportional to the altitude z. Thus for ψ_z put c^2z, where c is a constant, we get

$$\frac{d^2z}{dt^2}=c^2z,$$

if we suppose that simultaneously $z=0$ and $\frac{dz}{dt}=v_z=0$, the first integral of this will be (**18**)

$$v_z^2=c^2z^2. \tag{16}$$

By means of the observations cited above, we get

	1885. May 26.	May 30.	June 6.
$c^2=$	$\frac{0.11}{806\,800}$,	$\frac{0.25}{740\,500}$,	$\frac{0.29}{914\,300}$;

thus, by equation (16), at the measured heights,

v_z (calculated) $=298$,	430,	515cm./sec.;
while v_z (observed) $=220$,	260,	630cm./sec.

In the first two cases the calculated value is greater than the observed, and only in the third is it a little less; but in this case the observed value may be too great on account of errors of observation, the value being calculated from only three successive observations. Generally

we have not found vertical upward velocities so great as those given above, although horizontal eastward velocities amounting to more than 50 m./sec. are not uncommon, and the values of ψ_z are proportional to this.

Hence it seems that generally, at least in the southern part of the cyclone, where westerly winds blow in all the strata, the vertical upward velocity that would be produced by ψ_z and thus indirectly by these strong westerly winds, is greater than the one really observed. Now the observed velocity is produced jointly by ψ_z, the vertical pressure gradient ε, and the friction (which latter may be neglected); and thus it follows that ε must be negative.

This remarkable result may be expressed in the following manner: A part of the *vis viva* of the westerly winds prevailing in the cyclone is used in pumping the air up, by means of ψ_z, against the mean vertical temperature gradient ε, which tends to make it descend.

Now Prof. Hann has shown (**19**) that the mean temperature of the air column in the inflowing winds of a cyclone is generally so much lower than that of an anticyclone, that the vertical temperature gradient of the former must probably be directed downward. This result, although deduced from incontestable facts, has called forth much criticism, as the incontestable fact of an upward motion in cyclones seemed then inexplicable. Hann himself has pointed out that the mechanical energy (*vis viva*) of the upper current may be able to pump up the air of the cyclone against the pressure gradient. I believe that I have now shown how this transformation takes place. Of course, there may be modes of transformation other than the above, but this evidently will accomplish much. As to the *vis viva* of the upper currents of the cyclone, it may originate partly from the general atmospheric circulation, and partly from the mechanical energy produced by the cyclone itself from the latent heat of aqueous vapor. The proportion between these two sources of energy is probably quite variable.

There is another observed fact, which is explained by the action of ψ_z. Clement Ley and Hildebrandsson have observed that the cirrus clouds are much more numerous in westerly upper currents than in easterly. Now, since ψ_z is directed upward in the former and downward in the latter, the air will generally rise in a westerly current and thereby be cooled, so that the aqueous vapor contained in it will be condensed and form the ice needles of which the cirri consist. The reverse will take place in an easterly current.

The vertically deviating component ψ_z will also have a marked influence on the propagation of the cyclone center. Considering the well-known diagrams of Clement Ley and Hildebrandsson, we find that all strata, upper and lower, have a westward component of horizontal velocity in the northwest quadrant of the cyclone, but in no other. Thus the currents of all strata in this quadrant will have a downward acceleration (ψ_z negative) which after a time will give a downward velocity. This will reach its maximum somewhere to the west of the center, in the rear of the cyclone; then the currents entering the southwest quadrant will acquire an eastward component of horizontal velocity, which will give rise to an upward acceleration (ψ_z positive), by which the downward velocity acquired in the northwest quadrant will be gradually diminished and will vanish somewhere in the southern part of the cyclone. It therefore follows that the air will tend to sink down in the western half of the cyclone and that the reverse will happen in the eastern half. Obviously this will contribute to fill up the western part and empty the eastern part of the cyclone, so as to displace the center eastward. Certainly the propagation of a cyclone is a very complicated phenomenon which may have many coöperating causes, but I think the cause above named is in most cases a very efficacious one that may not be neglected.

REFERENCES AND NOTES.

(**1**) Partly extracted from the memoir: "Über die Einwirkung der ablenkende Kraft der Erdrotation auf die Luftbewegung." Bihang till K. Svenska Vetensk.-Akad. Handl., Bd. 15, Afd. 1, No. 14. Stockholm, 1890.

(**2**) The cause of the general trade-winds. Phil. trans., London, 1735.

(**3**) Mémoire sur les équations du mouvement relatif des systémes de corps. Jour., École polytechnique, t. **15**, cahier 24, p. 142.

(**4**) Motions of fluids relative to the earth's surface. Mathematical monthly (Runkle), 1859; and then in Ferrel's well-known "Researches."

(**5**) Études sur les mouvements de l'atmosphère. Christiania, 1876 and 1880.

(**6**) Traité de méchanique rationelle, par M. Ch. Delaunay. 2me. éd., Paris, 1857. p. 94. (I have not seen the first edition of this treatise.) The proof is reproduced in "Cours de mécanique" par M. Despérioux, etc. Avec des Notes par M. G. Darboux. t. 1. Paris 1884. p. 176 ffg. Also in Schell's "Theorie der Bewegung und der Kräfte" there is a geometrical proof of Coriolis' theorem, which is clear and rigid but rather long.

(**7**) Sprung. Lehrbuch der Meteorologie. Hamburg. 1885. p. 16.

(**8**) The proof is quite general; only for the sake of perspicacity we refer the position of the mobile immediately to the earth.

(**9**) Instead of these we may use the geographical latitude and the mean radius of the earth, without introducing any sensible error.

(**10**) Sprung. Lehrbuch der Meteorologie. p. 80–81.

(**11**) This is evident since then v is perpendicular to the equator.

(**12**) Because ω is equal to the quotient of 2π by a siderial day expressed in seconds of mean time $\omega = 2\pi/86\,164.09^{sec.} = 0.00\,007\,292\,1$.

(**13**) *See* Sprung's Lehrbuch. p. 16.

(**14**) Études sur les mouvements de 'atmosphère. Christiania, 1876, and Ztschr. d. Gesellsch. f. Meteorol., Wien, 1877, **12**: 53.

(**15**) Meteorologische Zeitschrift, Wien, 1888, **5**. Jhrg., p. 329.

(**16**) These measurements number more than 2,000. Although calculated some years previous to 1893 they have not yet been published in extenso, partly for want of time and partly for other reasons.

(**17**) This is according to Jordan, "Handbuch der Vermessungskunde," Stuttgart, 1877. 1. Bd., p. 532. Bauernfeind's inquiries furnish for a difference of height of 1 km. a mean error of ± 5.7 meters in the difference when determined barometrically. This, if due to a vertical gradient, would require a gradient of about 50 mm., which is obviously impossible.

For the rest, it would evidently require very exact barometric observations to determine even a horizontal gradient in so short a distance as 1 km.

(**18**) The second integral, $t - t_0 = \frac{1}{c}$ nat. log $\frac{z}{z_0}$, gives the time necessary for the vertical movement from z_0 to z. If $z_0 = 0$, it becomes infinite, which is rational, as we have supposed both acceleration and velocity equal to 0 at the ground ($z = 0$).

(**19**) *See* Meteorologische Zeitschrift, Wien, 1890, **7**. Jhrg. p. 226, 328, 457.

METEOROLOGY AT THE LICK OBSERVATORY.[1]

By WILLIAM GARDNER REED.

[Dated, University of California, Department of Geography, June 10, 1914.]

INTRODUCTION.

The Lick Observatory was founded under two deeds of trust by James Lick of San Francisco, the first dated July 16, 1874, and the second, September 21, 1875. These provided for "a powerful telescope, * * * and also a suitable observatory connected therewith." After a careful consideration of various possible sites (restricted to the State of California by the terms of the trust), the choice was Mount Hamilton, lat. 37° 20′ north, long. 121° 38′ west from Greenwich, altitude,[2] 4,209 feet above sea level, located among the Coast Ranges in the eastern

[1] The writer wishes to thank the members of the staff of the observatory, without whose cooperation and assistance this study could not have been made, and in particular to thank Director W. W. Campbell for the meteorological data, the photographs, and numerous other courtesies at the observatory.

part of Santa Clara County. The general location of the mountain and the larger topographic features of the region are best studied with the aid of the U. S. Topographic Atlas sheets for California. The topography of the region is shown in detail on the Mount Hamilton, Cal., sheet of the Topographic Atlas of the U. S. published by U. S. Geological Survey. The buildings are located on "Observatory Peak," the third of the highest peaks of the mountain, while on the higher peaks are placed the reservoirs for the water supply and hydraulic power. The general relations are shown by figure 3, a photograph of the observatory from Copernicus Peak, northeast of the observatory, and one of the two highest peaks of the mountain. An act of Congress, approved June 7, 1886, granted the trustees somewhat more than two sections of Government land including the summit of the mountain; later James Lick and Robert F. Morrow gave the trustees about 190 acres more, "so that the Observatory is secured forever against buildings in close proximity to it." The deed of trust provided that when the telescope and the observatory were completed they together with the land, should be conveyed to the Regents of the University of California, the corporation to which the government of the State University is entrusted. Any surplus of the $700,000 provided for the construction and equipment of the telescope and the observatory was to be turned over to the university and the income devoted to the maintenance of the observatory. The observatory was to be known as the Lick Astronomical Department of the University of California.

The actual work on Mount Hamilton began in the summer of 1880, and the regular astronomical work of the completed observatory on July 1, 1888. Since then the observatory has been in continuous operation. It is significant that the first volume issued from the observatory contains the following: "The Observatory is not primarily destined for a meteorological station. Its very exceptional situation, however, creates a responsibility on its part to engage to some extent in making routine meteorological observations, and a suitable outfit for this purpose has been obtained." [3] The results of the observations have been published from time to time by the Astronomical Society of the Pacific. A considerable volume was compiled by Astronomer C. D. Perrine, but not published for lacks of funds. Great credit is due many members of the staff and especially Dr. Perrine for the excellent condition of the record.

METEOROLOGICAL OBSERVATIONS.

Although the regular astronomical work of the observatory did not commence until July 1, 1888, meteorological observations have been made on Mount Hamilton since September 11, 1880. During the period of construction the observations were necessarily limited by the "other and more important occupation" of construction. However, the record during this time is surprisingly complete, chiefly because of the interest of Thomas E. Fraser, the superintendent of construction, by whom they were almost entirely made. Table 1 shows the observations made on Mount Hamilton for which the record is now available. Unfortunately the observing hours from November 9, 1885, to June 30, 1888, were not stated; no records are available for certain months, as will be seen from the table.

From July 3, 1888, meteorological observations were made at 7 a. m., 2 p. m., and 9 p. m. until September 30, 1908. Since October 1, 1908, observations have been made at 8 a. m. and 8 p. m., Pacific standard time. These observations have included pressure from a mercurial barometer, wet- and dry-bulb temperatures, wind direction and force on the Hazen scale (until Sept. 30, 1903), amount of cloud and occurrence of fog, both on the mountain and in the valleys. At the 2 p. m. and later at the 8 a. m. observations dial readings of the anemometer have been made; at the 9 p. m. and later at the 8 p. m. observations the maximum and minimum temperatures have been recorded and the self-registering thermometers set. Continuous autographic records of pressure, precipitation, and wind movement since 1888, and of air temperature since 1890 are also available.

The regular voluntary (cooperative) observer's reports have been sent to the Signal Service and the Weather Bureau. They have been printed in the climatological publications of those services. Summarized data have been published in United States Weather Bureau bulletins "L" and "W," and also by Director Holden, Dr. Perrine, and Dr. Maddrill, of the observatory staff, in the Publications of the Astronomical Society of the Pacific. The record from September 11, 1880, to October 31, 1885, was printed in full in the Publications of the Lick Observatory, Volume I.

INSTRUMENTS AND INSTRUMENTAL RECORDS.

The meteorological instruments were installed at the observatory in 1884 and 1885. These instruments included:

A Draper self-recording (weighing) mercurial barograph, magnifying five times.

A Draper self-recording (weighing) rain gage.

Two mercurial barometers, one by J. and H. J. Green of the Fortin cistern type, large bore (0.55 inch) tube, and one by John Roach, type not stated.

Eleven exposed thermometers, two maximum thermometers, and three minimum thermometers, all by Green; of these one minimum and two exposed were furnished by the Signal Service; the others were compared and certified by Yale College.

An anemometer of the United States Weather Bureau pattern, reading by dial to miles of wind travel (ratio, cup travel : wind travel :: 1 : 3) and recording electrically on a Weather Bureau type of "single register." [4]

The record of instruments used during the period of construction is far from complete. The type of thermometer in use before 1885 is not stated. In 1885 and 1886 a number of "standard" thermometers were furnished by Green; the Winchester Observatory of Yale College compared these with a standard. No record is available of the method of determining relative humidity, which was first recorded in 1886. It is probable, however, that the relative humidity was at that time obtained from wet- and dry-bulb readings according to the method then in use by the Signal Service.

[2] Altitude determined in 1887 under the direction of W. G. Raymond of the Department of Civil Engineering of the University of California as 4,209.42 feet to a bench on the marble floor of the observatory, by levels from the Market Street Station of the Southern Pacific Railroad in San Jose (elevation 88.7 feet, assumed). See Publ. Ast. Soc. Pacific, vol. 3 (1891) p. 370.

The altitude is stated by the United States Coast and Geodetic Survey as 1,298.9 meters (4,262 feet) on top of the 12" dome. ". . . the height of the small [12"] dome above the marble floor of the Lick Observatory is stated to be 40 feet 4 inches (12.3 meters); hence the height of the marble floor is 1,286.6 meters or 4,221 feet." See U. S. C. & G. S., Special Publication No. 4 (1900) "The Transcontinental Triangulation," by Charles A. Schott. This elevation is stated in "Triangulation in California, Part II," Appendix 5 of the Annual Report of the Superintendent for 1910, as belonging to class 3 "those [elevations] determined by nonreciprocal zenith distance measures, in which the probable error may be as much, in some cases, as ±10 meters." U. S. C. & G. S. Ann. Rept. for 1910 (1911) p. 308.

The altitude is stated in "A Dictionary of Altitudes in the United States" on the authority of the United States Geological Survey as 4,209 feet. U. S. G. S. Bull. 274 (1906) p. 96.

The altitude of the Southern Pacific track at San Jose is stated in U. S. G. S. Bull. 274, p. 124, on the authority of the U. S. C. & G. S. as 118 feet. The altitude of the base of the rail is stated on the present railroad profile as 98.91 feet above the mean sea level datum of the U. S. Geological Survey.

[3] Publications of the Lick Observatory of the University of California, 1887, vol. 1, pt. 9. Description of the Meteorological Instruments, by E. S. Holden, p. 78.

[4] For a more complete description of these instruments and their exposures see Publ. Lick Obs. Univ. Calif., 1887, vol. 1, pt. 9, pp. 78–81.

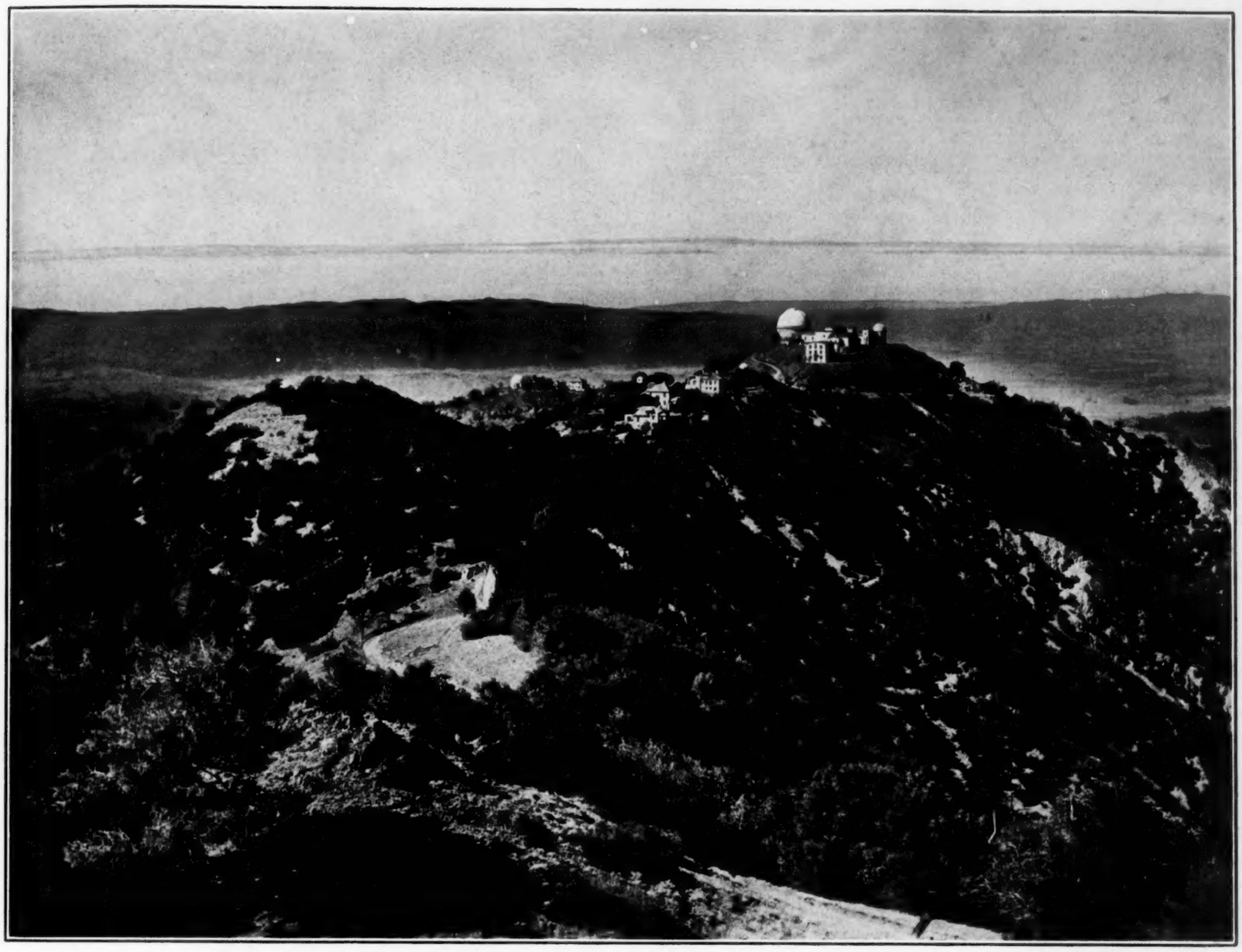

FIG. 1.—General view of Lick Observatory, on Observatory Peak of Mount Hamilton, Cal., from Copernicus Peak to the northeast. (Photo. by C. A. Bergmann, Apr. 2, 1914.)

FIG. 2.—Meridian Circle House (Lick Observatory) from the northwest. Note the louvred construction of the walls.

Thermometers are exposed in the double wall beyond the first window. The whirling device for the wet- and dry-bulb thermometers is between the observing slit and the second window.

The anemometer has occupied the position shown here since May 27, 1891; the wind vane since July 5, 1893. (Photo. by C. A. Bergmann, May 29, 1914.)

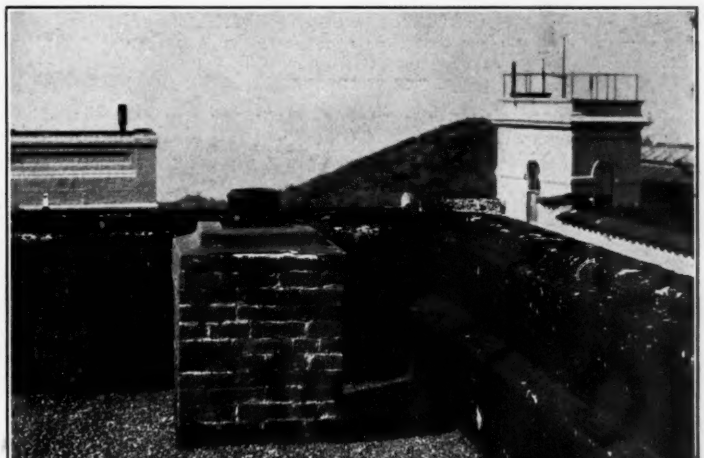

FIG. 3.—Details of rain gage exposure on the roof of Lick Observatory, 33 feet above the ground. The recording apparatus is immediately below. (Photo. by C. A. Bergmann, May 29, 1914.)

TABLE 1.—*Schedule of Meteorological Observations at the Lick Observatory.*

Dates.	Pressure.	Temperature.			Relative Humidity.	Precipitation.	Wind.			Weather.
		Daily.					Velocity.	Movement.	Direction.	
Sept. 11, 1880, to Sept. 26, 1880		Max	Min						Daily	Daily.
Sept. 27, 1880, to Dec. 1, 1880	Daily	Max	Min						Daily	Daily.
Dec. 2, 1880, to Dec. 21, 1880	6 p. m	Max	Min			Daily			6 p. m	Daily.
Dec. 22, 1880, to June 12, 1881	6 p. m	Max	Min			Daily				Daily.
June 13, 1881, to Feb. 28, 1882	6 p. m	Max	Min			Daily			6 p. m	Daily.
Mar. 1, 1882, to June 30, 1882		Max	Min			Daily			6 p. m	Daily.
July 1, 1882, to July 11, 1882	6 p. m	Max	Min			Daily			6 p. m	Daily.
July 12, 1882, to Aug. 31, 1882	6 p. m	Max	Min			Daily				Daily.
Sept. 1, 1882, to July 16, 1884	6 p. m	Max	Min			Daily			6 p. m	Daily.
July 17, 1884, to Sept. 30, 1884	6 p. m	Max	Min			Daily				Daily.
Oct. 1, 1884, to Nov. 8, 1885	6 p. m	Max	Min			Daily			6 p. m	Daily.
Nov. 9, 1885, to Feb. 8, 1886	(No record)									
Feb. 9, 1886, to July 30, 1886	Twice Daily.	Max	Min			Monthly			Daily	Daily.
July 31, 1886, to Sept. 30, 1886	(No record)									
Oct. 1, 1886, to Feb. 5, 1887	Daily	Max	Min	6 p. m?	6 p. m?	Daily	Daily max	Daily	Daily	Daily.
Feb. 6, 1887, to Apr. 4, 1887	Daily	Max	Min	6 p. m?	6 p. m?	Daily			Daily	Daily.
Apr. 4, 1887, to June 30, 1887	Daily	Max	Min	6 p. m?	6 p. m?	Daily	Daily max	Daily	Daily	Daily.
July 1, 1887, to July 31, 1887	(No record)					Total				
Aug. 1, 1887, to Aug. 17, 1887	Daily	Max	Min	6 p. m?	6 p. m?		Daily max	Daily	Daily	Daily.
Aug. 17, 1887, to Sept. 30, 1887	Daily	Max	Min	6 p. m?	6 p. m?	Daily			Daily	Daily.
Oct. 1, 1887, to Dec. 29, 1887	Daily	Max	Min	6 p. m?	6 p. m?	Daily	Daily max	Daily	Daily	Daily.
Dec. 30, 1887, to Jan. 31, 1888	Daily	Max	Min	6 p. m?	6 p. m?	Daily			Daily	Daily.
Feb. 1, 1888, to May 31, 1888	Daily	Max	Min	6 p. m?	6 p. m?	Daily	Daily max	Daily	Daily	Daily.
June 1, 1888, to June 30, 1888	Daily	Max	Min	6 p. m?	6 p. m?	Daily	([1])		Daily	Daily.
July 1, 1888, to Sept. 30, 1908	7a, 2p, 9p	Max	Min	7a, 2p, 9p	7a, 2p, 9a	Noon	Daily max	Daily	7a, 2p, 9p	Daily.
Oct. 1, 1908, to date	8a, 8p	Max	Min	8a, 8p	8p, 8p	Noon	Daily max	Daily	8a, 8p	Daily.

[1] May 27, 1891, the anemometer was lowered 10 feet to its present position on the Meridian circle house.

Atmospheric pressure.

Pressure was observed by means of an aneroid barometer until July 1, 1888, when the thrice-daily observations with the mercurial barometer began. In 1886 the correction for the aneroid was +0.21 inch, but the record does not show that this correction was applied. Since 1888 the pressure readings have been made from mercurial barometer No. 2839 Green. This instrument has a large-bore tube (0.55 inch inside); the scale is graduated in twentieths of inches to read directly to the argument of the Pulkova refraction tables by a vernier to 0.005 inch. The record had been entered originally to scale numbers, but converted to inches and thousandths to May, 1906. The pressures are available for each observation.

The barometer has been exposed, from the first, on the inner north wall of the Meridian Circle House; its location is shown by A in figure 4. The instrument hangs about 1½ inches from the wall and is held in a vertical position by a shelf around the cistern. The cistern is 4,212 feet above sea level (assuming the elevation of the marble floor is 4,209 feet). The readings and averages that have been issued from the observatory have been corrected for the temperature of the mercury only. The walls of the Meridian Circle House are double, the inner is of solid redwood and the outer of louvers of galvanized iron (see fig. 2). The space between the two walls is about 2 feet.[5] There is an ample chamber or attic over the observing room and the building is well ventilated, so that the inside temperature is the same as that of the outside air; the building is never heated artificially, and warming by solar radiation is prevented by the construction.[6] The Roach barometer was not at the observatory in 1902, and seems never to have been used for meteorological observations.

[5] For a more complete description of the Meridian Circle House *see* Publications of the Lick Observatory, 1900, 4:5.

[6] A series of comparisons made by R. T. Crawford in June and July, 1899, showed an average difference of temperature in the space between the walls and inside the Meridian Circle House of +0.03° and a maximum difference of +1.1°; in a series in October and November, 1899, the maximum difference was +2.1°, except for one difference of −3.7° at a time when the outside temperature was rising rapidly. *See* Publ. Lick Obs. Univ. Calif. 1913, 7:163–165.

A continuous record of pressure has been kept since July 5, 1888, by the Draper weighing mercurial barograph, magnifying five times. This instrument consists of a barometer tube supported at the top, with its lower open end dipping into a cistern hung on spiral springs. With a decrease of pressure mercury flows from the tube into the cistern, increases its weight, and stretches the springs; a pen attached to the cistern records on a moving sheet of paper behind the barometer. The record sheet is changed daily at noon. No correction for the temperature of the mercury need be applied to the readings of this barograph, as the weight of the mercury and not the length of the column is recorded. The correction for change in the springs with temperature is small enough to be negligible. The barograph is exposed opposite the rain-gage on the south wall of the east vestibule of the observatory (see D in fig. 4). The top of the mercury in the cistern is usually at about the same elevation above sea level as the fiducial point of the Green barometer in the Meridian Circle House.

Air temperature.

From September 11, 1880, until September 30, 1885, the thermometers were exposed in a wooden box at one of the cottages some 70 feet below the observatory and about 200 yards to the northeast. The records of temperature before and after October 1, 1885, are, therefore, not strictly comparable.[7] Since October 1, 1885, the exposure has been between the north walls of the Meridian Circle House about 7 feet above the ground. The location of the instruments is shown by B in figure 4, and the outside of the Meridian Circle House and the character of the ventilation by figure 2. Until September 30, 1908, there were exposed here maximum and minimum thermometers (Weather Bureau type) and wet- and dry-bulb thermometers forming a *stationary* psychrometer. Since October 1, 1908, wet-bulb readings have been made from a whirled thermometer under conditions which are discussed below. Both spherical- and cylindrical-bulb ther-

[7] *See* Perrine, C. D., in Publ. astrons. soc. Pacific, 1893, 7:124.

mometers have been used on the psychrometer, but no record is available of the service of each type, and there seems to have been an irregular succession of the two types as thermometers were broken in service.

Continuous records of temperature have been obtained from Richard seven-day thermographs since November 21, 1893, when a standard size (B. C. M.) instrument, reading from +5° to +100° F. was exposed with the mercurial thermometers. The record sheets have been changed on Mondays at noon. There a few thermograms for the year 1890 and continuous records from August 31, 1893, to November 21, 1893, but the exposure of the instrument during this time is not stated. This thermograph was compared with the exposed thermometer

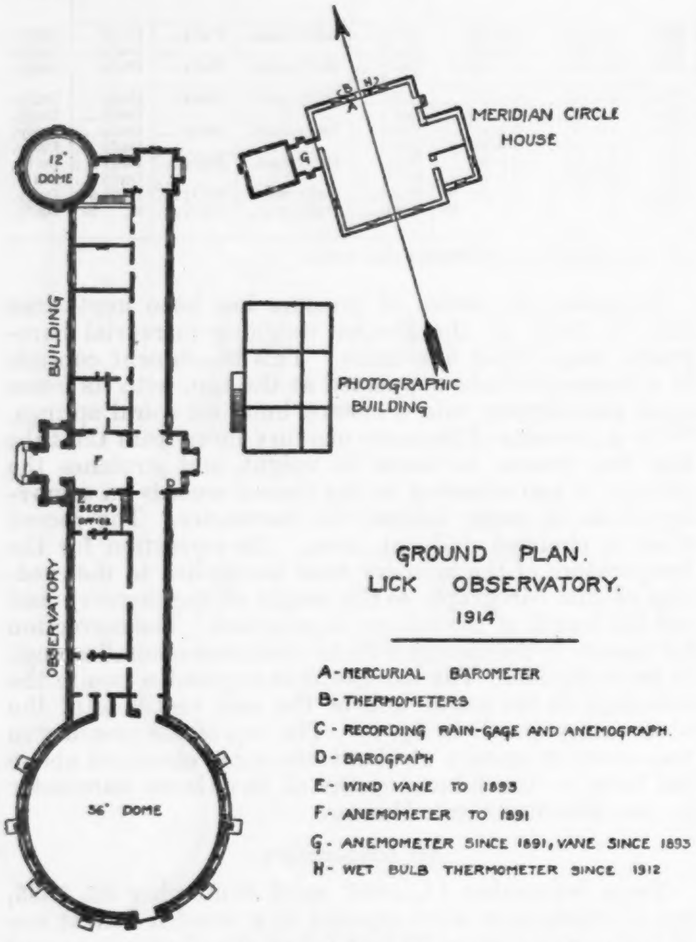

FIG. 4.—Plan of Lick Observatory, showing locations of meteorological instruments at various periods since September 11, 1880.

in September and October, 1894; the resulting corrections show the usual irregularity of the recording instrument but no correction was over three degrees and the average of all comparisons was less than half a degree. This thermograph continued in service until April 12, 1909. On March 1, 1909, a Richard thermograph, large size, reading from −25° to +115° F. was placed in service with the thermometers. This instrument is the property of the U. S. Weather Bureau; it has continued in service since its installation, and is now (1914) exposed with other thermometers between the walls of the Meridian Circle House.

Daily maximum and minimum temperatures have been observed since the first record (by Mr. Fraser), which included the maximum and minimum temperatures for September 11, 1880. The thermometers were exposed in a wooden box on the "flat" about 70 feet below and 200 yards northeast of Observatory Peak until October, 1885, when they were moved to their present location in the space between the walls of the Meridian Circle House. The ventilation of the early exposure in the wooden box was probably not as good as could be desired. Since October 1, 1885, the exposure has not been changed. Before June 30, 1888, maximum and minimum readings were usually made at 6 p. m., although there are some records of other times of observation. From July 1, 1888, until November 30, 1889, these observations were made at noon in Table 5, and an attempt has been made to adjust the maximum to the proper civil date by recording it as of the previous date. Since July 6, 1889, maximum and minimum readings have been made at the evening observation hour and the date regarded as the civil date on which the observations were made. The manner in which the readings were adjusted to the two times of observation and the time at which the instruments were set during the period of two records, noon and 9 p. m., are not stated in the record.

The early record does not state the type of thermometers used to obtain maximum and minimum temperatures, but it is probable that they were of the usual Signal Service pattern. Since the beginning of observations in the Meridian Circle House the self-registering instruments of the Signal Service and Weather Bureau type have been in service. When an observation was missed the maximum and minimum temperatures have sometimes been interpolated from the thermograph trace, but the record is clear on all occasions where this has been done.

Atmospheric moisture.

Relative humidities for the observation hours have been computed since October 1, 1886, and are available. Until July 3, 1888, there is no record of the type of instrument used; but, as the stationary psychrometer (wet and dry bulb thermometers) depending on natural ventilation was in service at the beginning of the regular astronomical observations in 1888, there is little doubt that this was the type of instrument employed. From July 3, 1888, wet- and dry-bulb readings have been made at the regular observation hours. Until September 30, 1908, the readings were still made from a stationary psychrometer, exposed between the north walls of the Meridian Circle House (see fig. 2 and B in fig. 4). From October 1, 1908, wet-bulb readings were made from a sling thermometer usually inside the Meridian Circle House, which, as already stated, is practically a large instrument shelter. This method was continued until March 12, 1912.[8]

Since May 9, 1912, psychrometer readings have been made with thermometers mounted on a Weather Bureau whirling apparatus located between the outer and inner north walls of the Meridian Circle House (see H in fig. 4 and fig. 6), about 10 feet east from the other thermometers. During most of this period the wet and dry bulb thermometers have both been mounted on the whirling apparatus, but at times dry-bulb readings have been made from the stationary dry-bulb in its original location (B in fig. 4). Since September 30, 1903, relative humidity has

[8] No record can be found of the date on which the use of the sling thermometer was discontinued, but the original record of observations shows a period of 42 days, beginning March 12, 1912, during which no wet-bulb readings were made. After May 9, 1912, fewer wet-bulb thermometers were broken, indicating a less dangerous method of ventilation (whirling apparatus). The recollection of the members of the observatory staff is that the change to the whirling apparatus was made about this time.

usually not been computed, although the observation of the wet-bulb thermometer has been continued and recorded at each observation hour; it is possible, therefore, to compute humidities, as all the observations are available.

A Weather Bureau hair-hygrograph by Friez, standard size, was placed in service March 1, 1909; since then there has been a continuous record of relative humidity from this instrument and the records are now on file at the Observatory. The record sheets are changed Mondays at noon. The hygrograph is exposed with the thermometers, and the thermograph between the north walls of the Meridian Circle House (see B in fig. 4).

The dew point was regularly computed from wet and dry bulb readings between July 3, 1888, and September 30, 1903; since that time the computations have not been made although the wet- and dry-bulb temperatures are available so that computations may be made; the dew points since March, 1909, may be computed from the hygrograph record.

Precipitation.

Rainfall and melted snow has been measured by the Draper self-recording rain-gage. The receiving funnel of the gage is exposed on the roof of the observatory over the east vestibule. (See fig. 4, C, and fig. 3.) The rim of the funnel is a circle 7⅝ inches in diameter; it is 3 feet above the roof and about 2 feet from the northeast corner of the parapet, which rises 2 feet 8 inches above the roof; figure 3 shows the relations between the gage, the roof, and the parapet. The rim of the funnel is 33 feet above the ground and 4,239 feet above sea level.

The recording apparatus is immediately below the funnel, on the north wall of the vestibule. (See C in fig. 4.) This consists of a bucket carried on spiral springs; an ink pencil attached to the bucket makes a trace along the zero line at the top of the record sheet when the bucket is empty. Precipitation falling into the funnel is carried by a tube to the bucket below; the funnel is warmed by the office below and also by a lamp (now a 32-candlepower carbon electric lamp) which is kept burning during snowfall so that such snow as is caught by the funnel is melted and flows into the bucket. As water flows into the bucket the springs are extended and the recording pen is carried down the sheet until the 0.50-inch mark at the bottom of the sheet is reached; at this point the weight of the water in the bucket is sufficient to overcome its stability, the bucket automatically empties by tipping, and is then carried up by the springs until the pen again reaches the top of the record sheet. An adjustable weight is attached to the bucket and so placed that the tip occurs at the instant when the 0.50-inch mark is reached. After the bucket rises to the top of the record sheet, the water continues to flow in and the record of the next 0.50 inch is made in the same manner as the first. The record sheets are changed daily at noon, the same sheet being used repeatedly unless it has a record of precipitation. Only the sheets which have records of precipitation are filed, but a record is kept of days with rain so there is no doubt that the record is complete for the period since 1888.

During the period of construction a rain gage of unknown type was used; this gage was placed in service December 2, 1880. The precipitation for November, 1880, was estimated at half an inch at the time and appears as such in Table 3. There is no record of the time at which the observations from the Draper gage began; apparently the gage was in place early in 1886, but the first record sheet in the file is dated September 30, 1888. The daily report shows that this was the second rain of the rainfall year beginning July 1, 1888; 0.02 inch fell on August 29, 30, and 31. There are no records of stick measurements of rainfall, the amounts from the record sheets being reported to the Signal Service and, later, to the Weather Bureau.

Records of snowfall and of snow on the ground are imperfect. Because of the exposed position of the observatory, snowfall measurements here are of very doubtful value. The relation between the amount of snow caught by the funnel of the rain gage and the actual snowfall has not been determined and such determination will be exceedingly difficult. The recorded precipitation includes the water-equivalent of the snow caught by the funnel as this snow is at once melted and flows to the recording bucket. The questions of loss by evaporation during melting and of loss in the tube have never been studied here; but both these losses are probably a small percentage of the necessary loss, due to wind during precipitation.

Wind direction.

During the period of construction the general wind direction for the day was at first estimated. With the beginning of the thrice-daily observations in July, 1888, and probably since 1885, wind direction was observed by means of a vane about 11 feet long with a Weather Bureau type of head but a single board tail measuring about 5½ feet long by 11 inches wide. This vane was mounted on a staff about 20 feet high, located directly over the Secretary's office. (See E in fig. 4.) On July 5, 1893, the vane was moved to the northeast corner of the tower by the Meridian Circle House; this location is shown by G in figure 4 and in figure 2. The new exposure probably gives the true direction of the wind more nearly than the old. The vane is mounted on a staff 7 feet in height, making the vane 42 feet above the ground and 4,248 feet above sea level, referred to the bench on the marble floor of the observatory. The daily wind directions reported to the Weather Bureau have usually been computed from the records of wind direction at the observation hours.

Wind velocity.

Wind velocity has been recorded from dial readings of a Robinson cup-anemometer of the Signal Service pattern (arms about 7 inches to the centers of the cups). The anemometer was mounted on a staff about 20 feet high, above the roof over the central portion of the observatory until May 27, 1891. Its then position with relation to the building is shown by F in figure 4. The cups were 50 feet above the ground and 4,256 feet above the sea-level plane to which the bench mark on the marble floor refers. Since May 27, 1891, the exposure has been over the tower by the Meridian Circle House on a staff about 5 feet long. This exposure is shown by G in figure 4, also by figures 2 and 3. The cups are 40 feet above the ground and 4,246 feet above sea level. The present exposure is probably good for all directions except the southeast, the direction from which the strongest winds generally come. Comparisons between the exposure over the observatory and that over the tower (points F and G in fig. 4), made in January, 1895, when the wind was almost continuously from the southeast, indicate that the recorded velocities of the southeasterly winds

are considerably lower than the indicated velocities from the old exposure. The recorded velocities of south-easterly winds are also lower than the recorded velocities of winds of the same apparent force from other directions.

All records of wind velocity are those recorded directly from the cup travel by the fixed ratio of the instrument (3:1) indicated by the dial as miles of wind movement. No attempt has been made to correct the dial readings to the true wind movement and velocity. In addition to the dial readings, wind travel has been recorded electrically on a Signal Service pattern anemograph ("single register"); this register is located just west of the recording device of the rain gage in the vestibule of the Observatory (C in fig. 4). The anemometer and the single register were installed in 1884,[9] but the file of record sheets at present at the observatory begins with July 1, 1888. Records of dial readings and total indicated wind travel begin October 1, 1886, and, except for periods when the anemometer was out of service because of ice or other hindrances, are continuous from that date. Originally the circuit to the single register was closed at every mile of indicated wind travel (one-third mile of cup travel) and a record made on the sheet. On June 7, 1889, some of the contact pins were cut off, so that the circuit was closed and the record on the sheet marked every fifth mile of indicated wind travel.

NONINSTRUMENTAL OBSERVATIONS.

A record of wind velocity on the Hazen scale is available for the observation hours from July, 1888, to September, 1903, in addition to the instrumental record of wind movement.

The amount of cloud in tenths of the sky has been estimated at each observation hour since July 3, 1888; the occurrence of fog in the valleys below has also been recorded. Before July, 1888, there are occasional notes of the occurrence of fog, but no regular record seems to have been kept. The general character of the day has been reported from the record of the regular observations, but there is no record aside from the regular observation hours.

Records of occasional phenomena have also been entered from time to time on the reports and are recorded in the observation books. The completeness of these records has, however, varied widely with the individual observers. The necessities of the astronomical work of the observatory, which is its main business, have prevented a complete record except at the observation hours.

OBSERVERS.

The actual observations have been made for the most part by the members of the astronomical staff since July 1, 1888; before that time they were made chiefly by Mr. Thomas E. Fraser, the superintendent of construction. A full list of the observers, with the periods of their services will appear in a future publication of the observatory.

METEOROLOGICAL CONSTANTS OF THE STATION.

Table 2 shows in summarized form the principal changes, with dates, in the constants of the station. The instruments in service May 30, 1914, are listed in Table 2, which also states the instruments now on the property list of the Weather Bureau as loaned to the Director of the Lick Observatory. All elevations above sea level depend upon the value, 4,209.46 feet, adopted as the altitude of the bench mark on the marble floor of the observatory.

Table 2.—*Meteorological instruments in service May 30, 1914, at Lick Observatory, Mount Hamilton, Cal.*

[ϕ=37° 20′ N; λ=121° 38′ W. H=4212 ft.; h_t=7 ft.; h_r=33 ft.; H_r=4239 ft.; H_a=4246 ft.; h_a=40 ft.]

Instrument.	Pattern.	Number.	Maker.
Mercurial barometer	Fortin cistern, 0.55-inch bore	2839	Green.
Barograph	Draper weighing mercurial		Draper.
Dry-bulb thermometer	Spherical bulb, Signal Service	24154	Green.
Wet-bulb thermometer *	Cylindrical bulb, Weather Bureau	5975	Do.
Whirling apparatus*	Weather Bureau. *		Friez.
Maximum thermometer	do	888	Green.
Minimum thermometer	do	8915	Do.
Thermograph *	Richard, large size	8990	Richard.
Hygrograph	Weather Bureau	14	Friez.
Rain-gage	Draper self-recording (weighing)		Draper.
Wind vane	11-foot, flat tail		
Anemometer	Signal Service		
Anemograph	Signal Service single register		Hahl.

* Property of the United States Weather Bureau.

PRECIPITATION AND TEMPERATURE OF MOUNT HAMILTON.

The monthly, seasonal, and annual rainfall of Mount Hamilton since the beginning of the record is shown by Table 3. The data are those observed by the observatory, but the results have been checked by the records of the United States Weather Bureau and all differences investigated by reference to the original observations. The only important differences are to be found in certain winter months where snowfall was indicated in the reports sent to the Weather Bureau at the date of the fall, but the catch of the rain gage, including melted snow, reported by storms only. In Table 3 the catch of the rain gage has been reported in all cases; this includes rain, melted snow, and precipitation from clouds surrounding the observatory which might be classed as fog at times; the record is that of the total registered catch of the rain gage and in most cases is probably under rather than over the actual precipitation owing to the exposed location of the gage.

Table 3.—*Monthly, seasonal, and annual precipitation at Lick Observatory, Mount Hamilton, Cal.* (*Inches.*)

[H_r=4,239 ft.; h_r=33 ft.]

Season.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Seasonal.	Year.	Annual.
1880-81	0	0	0	0	0.50	9.68	3.51	5.99	1.13	0.98	0.09	0.33	22.21	1881	23.09
1881-82	0	0	0.10	0.33	0.91	9.72	3.55	2.90	5.40	4.70	0.48	1.06	29.15	1882	29.63
1882-83	0	0	0	6.16	3.45	1.93	3.10	3.75	8.66	2.66	7.55	0	37.26	1883	32.05
1883-84	0	0	0.65	2.15	1.48	2.05	5.60	12.76	16.35	11.96	1.24	3.85	58.09	1884	90.12
1884-85	0	0.15	0.65	3.71	0.01	33.84	1.99	0.57	1.15	2.08	0.16	0.36	44.67	1885	18.23
1885-86	0	0	0.15	0.05	1.92	9.80	4.44	1.80	5.77	6.79	0.70	0	31.42	1886	25.26
1886-87	0	0	0	0.60	2.82	2.34	2.83	7.80	1.39	5.75	0.25	0.30	24.08	1887	30.93
1887-88	0.04	0	0.33	0.09	0.90	11.25	10.04	1.38	3.40	0.68	1.25	0.67	30.03	1888	25.46
1888-89	0	0.02	0.49	0.03	3.27	4.23	1.04	1.42	6.17	1.92	3.21	0.05	21.85	1889	35.84
1889-90	0	0	0	4.38	4.46	13.19	7.93	6.60	4.39	1.79	2.42	0	45.16	1890	29.92
1890-91	0	0	0.80	0.02	0.58	5.39	1.38	7.12	4.10	3.08	1.01	0.57	24.05	1891	28.07
1891-92	0	0	0.28	0.61	0.38	9.54	1.97	2.99	5.98	1.90	3.52	0.32	27.49	1892	34.16
1892-93	0	T.	0.24	1.38	10.30	5.56	3.29	3.45	8.99	3.61	0.95	0.16	37.93	1893	29.18
1893-94	0	0	0.48	0.66	4.01	3.58	9.74	10.52	2.54	0.89	2.78	0.64	35.84	1894	44.49
1894-95	0.02	T.	1.64	2.98	0.84	11.90	10.00	3.08	1.46	2.30	2.39	0	36.61	1895	25.72
1895-96	0.01	0	0.08	0.78	2.46	3.16	9.54	1.08	3.83	6.70	2.10	0.02	29.76	1896	36.64
1896-97	T.	0.28	0.47	1.85	5.86	4.91	3.50	7.42	6.45	0.82	0.28	0.38	32.22	1897	24.38
1897-98	0	0	0.07	1.25	1.51	2.70	2.30	4.16	2.04	0.84	2.41	0.38	17.66	1898	17.11
1898-99	0	0	0.29	1.33	1.23	2.13	5.63	0.75	11.11	1.40	1.47	0.39	25.73	1899	36.32
1899-00	0	0.12	T.	3.37	4.92	4.16	3.26	1.70	3.37	4.06	1.35	T.	29.31	1900	27.30
1900-01	0.01	0.02	0.08	3.48	7.76	2.21	5.76	5.92	1.98	3.33	1.07	0.02	31.64	1901	25.90
1901-02	0	0.05	1.08	2.19	2.89	1.61	1.44	9.14	5.19	2.61	1.19	0	27.39	1902	27.78
1902-03	0	0	0	2.09	3.01	3.11	8.86	2.20	9.89	1.12	0.05	T.	30.33	1903	31.55

[9] *See* Publications of the Lick Observatory, 1887, 1, pt. 9, p. 80-81.

TABLE 3.—*Monthly, seasonal, and annual precipitation at Lick Observatory, Mount Hamilton, Cal.*—Continued.

Season.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Seasonal.	Year.	Annual.
1903-04..	0	0	T.	0.37	7.67	1.39	1.98	9.53	8.06	4.38	0.45	0.03	33.86	1904	35.21
1904-05..	T.	0.05	2.33	2.51	2.05	3.84	4.04	3.89	5.91	1.36	2.27	0	28.25	1905	23.04
1905-06..	0	0	0.02	0	3.50	2.05	11.66	5.76	9.72	1.81	3.15	1.15	38.82	1906	45.76
1906-07..	0	T.	0.28	0.05	1.92	10.26	9.81	4.69	12.90	1.14	0.42	0.92	42.39	1907	39.47
1907-08..	T.	0	0.01	1.62	0.18	7.77	5.02	4.26	1.95	0.70	2.39	0.02	23.93	1908	21.30
1908-09..	0	0	0	1.37	2.63	2.96	18.18	9.49	4.05	0.03	0.13	0	38.84	1909	43.11
1909-10..	0	0	0	1.77	2.59	6.87	6.24	3.12	3.28	0.91	0.12	0.07	24.97	1910	17.70
1910-11..	0.04	0	0.25	1.06	0.94	1.77	15.76	4.37	7.00	1.35	0.75	0	33.29	1911	34.12
1911-12..	0	0	0	0.46	1.21	3.22	4.44	0.50	3.96	2.70	1.31	0.44	18.24	1912	20.92
1912-13..	0	0	2.01	0.94	2.34	2.28	5.42	0.48	3.40	0.94	1.60	0.07	19.48	1913	23.46
1913-14..	0.06	0.10	0	0	5.34	6.05	11.57	5.24	1.51	2.01	1.80	.....	.....	.....	.....
Averages	0.01	0.02	0.38	1.55	2.82	6.07	6.03	4.55	5.37	2.62	1.54	0.34	31.30	.....	.....

The temperature data for Mount Hamilton have been compiled in Table 4. The data since July, 1888, have been compared with those published by the Weather Bureau, and are in essential agreement with them; in the few cases of disagreement the data for the months have been computed from the original record and the means derived from the new computation entered in the table; all additions have been made by an adding machine. The averages have been determined from the means entered in the table. The extreme temperatures, presented in Table 5, have been compiled from the original records. Owing to the differences in the exposure conditions the extremes before October 1, 1885, have been separated from those observed since that date. This separation has not been made for the means, as it is probable that the difference between the older means and the true mean temperatures for those months is less than the error they introduce into the averages, and it is desired to show the complete record of the station.

TABLE 4.—*Monthly and seasonal mean temperatures at Lick Observatory, Mount Hamilton, Cal.* (°F.)

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Seasonal means.
1880-1881......	.....	.....	65.9	61.6	48.7	43.0	42.5	44.0	46.4	54.6	59.0	62.2	.....
1881-1882......	69.4	66.7	62.2	45.6	38.4	42.8	35.8	35.4	41.7	46.2	63.4	63.2	50.9
1882-1883......	72.5	73.3	68.0	50.6	44.1	47.2	45.2	39.2	51.0	43.6	53.0	67.8	54.6
1883-1884......	74.0	70.0	69.6	50.8	50.0	46.4	46.0	40.0	39.2	43.6	54.4	55.4	53.3
1884-1885......	62.4	72.8	60.6	56.2	52.5	41.0	49.0	47.1	51.9	50.0	57.6	58.8	55.0
1885-1886......	68.4	75.0	66.4	61.5	.....	.....	.....	49.4	41.2	46.6	55.1	65.2	.....
1886-1887......	46.2	.....	.....	51.3	48.3	50.4	43.6	33.0	51.4	46.9	53.8	61.3	.....
1887-1888......	.....	69.0	67.2	59.2	53.4	40.6	35.6	44.6	41.9	54.6	53.8	55.6	.....
1888-1889......	68.8	73.8	72.5	59.4	48.2	46.2	41.1	45.6	46.1	50.3	54.4	68.8	56.3
1889-1890......	72.3	72.6	68.6	53.7	49.9	34.8	30.6	36.6	41.3	48.0	46.6	58.2	51.1
1890-1891......	70.2	70.5	67.4	58.8	56.5	46.6	42.0	35.8	41.4	44.7	52.0	55.2	53.4
1891-1892......	71.4	72.6	60.7	59.1	52.1	35.8	44.1	42.4	42.6	42.8	52.6	57.2	52.8
1892-1893......	67.0	71.9	63.4	54.8	51.8	42.1	51.3	39.9	37.2	41.0	51.6	58.8	52.6
1893-1894......	67.9	71.8	55.4	51.0	46.9	44.8	35.9	35.6	40.4	49.4	51.6	52.6	50.3
1894-1895......	71.3	71.6	63.5	55.5	57.6	37.2	36.4	45.6	42.8	47.2	52.2	65.2	53.8
1895-1896......	67.2	70.4	59.0	59.9	47.9	41.4	45.2	46.5	43.4	37.6	46.6	64.6	52.5
1896-1897......	73.2	67.8	61.7	57.8	44.8	45.4	41.5	36.3	32.8	51.0	58.0	57.8	52.2
1897-1898......	70.8	71.5	60.4	51.7	46.3	43.0	35.8	42.8	39.1	50.8	47.9	62.0	51.8
1898-1899......	71.4	71.2	61.8	56.0	46.5	43.1	42.5	41.0	39.6	47.6	46.3	63.7	52.6
1899-1900......	71.6	61.3	69.8	52.7	46.9	45.6	47.5	43.0	48.1	43.0	52.8	63.8	53.8
1900-1901......	71.6	62.0	56.2	57.2	51.0	47.2	39.7	40.4	44.0	44.8	50.1	59.8	52.0
1901-1902......	69.9	69.4	58.8	56.5	50.4	46.6	40.9	39.0	36.6	41.3	46.4	58.4	51.2
1902-1903......	66.7	66.9	68.2	53.0	41.6	41.8	43.7	34.9	40.0	43.7	54.0	61.6	51.3
1903-1904......	64.0	67.4	63.6	59.8	48.2	47.2	41.4	39.6	38.7	45.6	56.6	65.0	53.2
1904-1905......	66.0	72.4	65.0	55.6	51.0	43.0	43.4	43.1	44.4	47.2	45.9	59.6	53.0
1905-1906......	71.3	70.2	62.2	56.4	46.2	41.6	43.3	43.6	40.2	45.6	48.6	56.4	52.1
1906-1907......	75.2	71.8	63.4	58.6	43.7	42.2	34.2	48.2	37.4	49.2	51.4	57.6	52.7
1907-1908......	67.1	66.4	57.5	54.5	49.6	42.4	40.1	38.9	44.6	50.7	46.9	58.1	51.4
1908-1909......	74.4	70.2	62.8	51.6	50.7	40.6	39.2	36.8	37.4	50.6	51.6	60.6	52.2
1909-1910......	65.7	69.8	64.1	55.3	44.4	38.0	35.6	38.3	47.0	50.9	57.0	57.6	52.0
1910-1911......	70.5	72.0	62.4	58.2	48.0	44.7	38.9	32.9	44.0	44.6	48.4	62.4	52.2
1911-1912......	73.4	66.9	56.0	53.8	48.6	39.0	42.8	43.3	37.3	40.0	51.6	59.2	51.0
1912-1913......	65.5	64.6	60.4	50.1	49.8	40.4	37.6	39.7	41.2	43.8	53.8	55.2	50.2
1913-1914......	67.0	69.5	66.0	58.0	43.8	39.0	39.6	42.8	49.9	45.8	54.6	.....	.....
Averages....	68.9	69.8	63.4	55.5	48.2	42.8	41.0	40.7	42.4	47.2	52.3	60.9	52.5

TABLE 5.—*Extreme temperatures at Lick Observatory, Mount Hamilton, Cal., from Sept. 11, 1880, to May 31, 1914* (°F.).

Month.	From September 11, 1880.				From October 1, 1885.			
	Max.	Date.	Min.	Date.	Max.	Date.	Min.	Date.
	°F.		°F.		°F.		°F.	
July.......	97	14, 1886	30	3, 1902	97	14, 1886	30	3, 1902
August....	96	17, 1885	34	16, 1902	93	23, 1888	34	16, 1902
September	93	1, 1882	30	25, 1901	91	9, 1888 18, 1913	30	25, 1901
October...	90	12, 1901	28	29, 1901	90	12, 1901	28	29, 1901
November.	88	12, 13, 1892	13	19, 23, 1900	88	12, 13, 1892	13	19, 23, 1900
December.	72	23, 1899 6, 1900	17	25, 1899 20, 1911	72	23, 1899 6, 1900	17	25, 1899 20, 1911
January...	74	6, 1893	6	14, 1888	74	6, 1893	6	14, 1888
February..	74	18, 1893	12	12, 1884	74	18, 1893	13	4, 1899
March.....	80	29, 1881	18	14, 1881	76	26, 1887	19	20, 1897
April.......	82	27, 1881	21	13, 1883	80	13, 1888	22	12, 1911
May.......	90	19, 1881	21	1, 1901	88	31, 1910	21	1, 1901
June.......	92	6, 1883	29	3, 1902	90	23, 1895	29	3, 1902
Year.	97	July 14/86	6	Jan. 14/88	97	July 14/86	6	Jan. 14/88

NOTE.—Since October 1, 1885, the exposure has been the same, 7 feet above the ground between the north walls of the Meridian Circle House. Before October 1, 1885, the exposure was in a box in the saddle about 200 yards northeast of Observatory Peak and about 70 feet lower.

CONCLUSION.

The meteorological record at Mount Hamilton has been kept continuously for nearly 34 years; during the last 28½ years the exposure of the instruments, except the anemometer and vane, has been unchanged; and during the last 26 years the administration and the routine have remained unchanged. The record, therefore, furnishes a considerable body of data for a study of the mountain climatology of central California. It is especially fortunate that a regular station of the Weather Bureau is situated at San Jose in the Santa Clara Valley, near the foot of the mountain; there are, consequently, available records of undoubted value for a comparison of the climate of the mountain with that of the valley below. Such a study is now contemplated by the University of California and it is hoped that the results of the study will furnish a better understanding of the climatology of the Coast Range region of this portion of the State than has been possible heretofore.

THE NEGLECT OF ATMOSPHERICS.

The great neglect of the study of the atmosphere, both by students and teachers in universities and colleges, as compared to the study of other subjects that are less important to the human race, is common both to Europe and America. It can only be explained by a recognition of the fact that the study of the atmosphere in general has not yet been pushed to such a degree as to have attained great practical importance in the business interests of the world. We have not yet learned to control the storms or to make detailed, accurate long-range predictions of wind and weather. But the rapid approach of this desirable attainment will be greatly facilitated and indeed absolutely assured, when the study is taken up in earnest from the point of view of the experimental physicist rather than that of merely observational climatology. The mind, the brain, the intellect, not brawn and muscle, are the powers that Man must use in his search for the keys that will open the flood gates of the clouds and the winds.

The rapid progress of our knowledge of the upper atmosphere, experimental work with balloons, the prog-

ress in aeronautics, all point to the fact that the scientific study of the atmosphere needs to be rapidly advanced in order to keep up with the branches of practical work and the business enterprises that these have instigated.—[C. A.]

THE WEATHER VERSUS COAL-MINE DISASTERS.

The great loss of life attending the operation of our mines many years ago led to the appointment of commissions to see what could be done to diminish or prevent such accidents, which were said to be due to the sudden exhalation of gases within the mines and their explosion by contact with the miners' lamps. It was even thought that forecasts of low atmospheric pressure might be made useful to the miners.

The present state of our knowledge of this subject is shown by the following extracts from letters communicated by the Acting Director of Mines, at Washington, D. C.:

The matter of the possibility of giving warning to mine managers at times of low barometer has been carefully considered by the staff of the Bureau. The investigations both in this country and abroad do not justify the belief that any particular relation can be established between explosions of fire damp and the low barometric conditions. It is believed that those are in error who think that the contrary has long been recognized. The Royal Commission on Explosions in Mines deprecated the issuance of colliery warnings by the Meteorological Service of Great Britain. Compilations of statistics of explosions have shown no increased dangers from low barometric conditions; in fact, in some cases the opposite has been indicated, but this seems probably a matter of chance.

It is true that if gas is allowed to accumulate in the open workings of mines it will tend to come out when there is low atmospheric pressure, but the accumulation of fire damp in old workings is not usual in the mines of this country. On the other hand, in active workings where gas is encountered, in almost all cases it issues at a vastly greater pressure than atmospheric; sometimes it will be several times atmospheric pressure, and, therefore, any slight differences in the atmospheric pressure could not possibly affect its issuance.

As far as the Dr. Haber fire-damp signal is concerned, that is not for forecasting, but it is to make known when there is a dangerous accumulation of fire damp. It depends upon the difference of density of fire damp as compared with air, which is manifested through a difference in tone of two whistles. In correspondence it does not appear that the device has reached a stage where it can be considered practicable; nor does Dr. Haber claim that it will show less than 1 or 2 per cent, which is shown by the ordinary safety lamp.

A later note from the Acting Director states:

It may be further mentioned that, while the engineers of the Bureau do not believe that it is wise to attach too much importance to the effect of low barometer, yet they are by no means neglecting to obtain the records in every case, after a mine explosion, from the Weather Bureau, supplemented by local records where such are to be had and, further, they are continuing to study this situation in gaseous mines whenever opportunity presents. Therefore the opinions expressed in the letter above mentioned must be considered tentative.

THE ULTIMATE CAUSE OF OUR WEATHER.

During the past two centuries meteorology has become a mass of observational data. From this we have compiled numerous statistical averages of the data in reference to time, locations, the position of the sun, and numerous other interesting and instructive relations. Everything seems tending toward the realization of man's hopes, viz, the determination of the reasons for the existence of this variable weather and its eventual forecasting. Our hypotheses and theories are plausible and rational, but we are still almost as far from the goal as our colleagues the magneticians.

In a recent lecture by Dr. L. A. Bauer, he concludes by some remarks:

THE CAUSE OF THE EARTH'S MAGNETISM.

Possibly by this time, if not before, you may have said to yourselves: "Granted that the compass needle points north and south because the earth itself is a magnet, what, in turn, causes the earth's magnetism, why are the magnetic poles not only not situated at the geographical poles, but not even diametrically opposite one another; or why, instead of wandering to and fro with the lapse of time, do not the magnetic poles remain fixed in position?" Lest any of these questions should cause you sleepless nights, let me say that, for the present at least, it would appear the better policy to confess ignorance. We may also take comfort in the fact that if the student of the earth's magnetism has not yet discovered the true cause of his science, neither has the investigator of magnetism, in general, been able as yet to answer the question: "What is a magnet?"

The most famous astronomer of his time, Simon Newcomb, one day entered the office of the associate editor of the Standard Dictionary, expressing his dissatisfaction with the tentative definitions for the words "magnet" and "magnetism," as based, in the absence of authoritative knowledge of the causes, simply upon the properties manifested. He was promptly requested to try his own hand. After writing and erasing alternately for an hour or more, he finally, with a hearty laugh, submitted the following pair of definitions: "Magnet, a body capable of exerting magnetic force." "Magnetic force, the force exerted by a magnet." Equivalent definitions will be found in Ambrose Bierce's "Devil's Dictionary" and, in explanation, the author cynically remarks that they were "condensed from the works of 1,000 scientists who have illuminated the subject with a great white light, to the inexpressible advancement of human knowledge."

But after all, it would seem that it is not so much the Why and Wherefore as the Therefore by which human progress is most advanced. Man, as the astronomer Littrow jokingly remarked, is "das Ursachen-Thier" who is ever incited and stimulated by his inquisitiveness as to the *cause* of things. Though he may never determine the "Endursachen" or ultimate causes, his inquiries lead him to acquire a vast amount of data with the aid of which he at least finds out the laws governing the phenomena under investigation.

The accumulation of data must at present be the chief aim of the student of the earth's magnetism. Perhaps no other subject can furnish more instances that, while theories as to the Why and Wherefore, though propounded by the most enlightened of the age, are short lived, the facts accumulated by observation and experience remain as permanent acquisitions to the storehouse of human knowledge.

THE PLANETS AND THE WEATHER.

By W. J. HUMPHREYS, Professor of Meteorological Physics.

[Dated, U. S. Weather Bureau, Washington, July 9, 1914.]

The weather and all its endless and manifold changes ultimately depend upon the reception and emission of radiant energy by the atmosphere and the surface of the earth. It is the eternal ebb and flow and ceaseless readjustment to equality of these two streams of energy that determine the temperatures of the atmosphere and establish its every temperature gradient. It is these, in turn, temperature and temperature differences, that give us evaporation, condensation, pressure gradients, wind velocities, and all or nearly all other elements of weather and weather changes.

Hence, nothing can influence the weather that has no effect on either of these energy streams. Conversely, everything that does modify these streams, either generally or locally, has a corresponding control over all weather elements and the climates of all places.

Do the planets, then, in any way affect the amount or distribution of radiant energy received by or lost from the earth? If they do, in that proportion, and in no greater, they obviously determine the weather and control its changes.

Now, there are just two known ways by which the planets can change the amount, but not the distribution,

of radiation reaching the earth, and, therefore, its temperature and other weather factors: (1) By changing their own brightness, through change of distance and phase; (2) by changing the earth's distance from the sun through the perturbations they produce in its orbit.

Change in planetary brightness.—The approximate effect of the first of these factors—change in the planetary brightness—is easily calculable. The light of all the planets, each at its maximum, is approximately that of 260 stars of the first magnitude, as the accompanying table shows, Venus alone contributing the light of about 209 such stars. On the other hand, the light of the sun is equal, roughly, to that of 73,000,000,000 first magnitude stars.

TABLE 1.—*Relative brightness of the planets.*

Name.	Stellar magnitude.	Date.	Equivalent, in first magnitude stars.
Mercury	−1.9	May 1, 1915	14.5
Venus	−4.8	Dec. 27, 1914–Jan. 6, 1915.	209.0
Mars	−1.3	Jan. 3–5, 1914	8.3
Jupiter	−2.5	Sept. 4–25, 1915	25.0
Saturn	−0.3	Dec. 16–25, 1914	3.3
Uranus	6.0	Opposition	0.01
Neptune	7.7	....do	0.002

Venus and Mercury, being inner planets, change in brilliancy from maxima of the equivalent of about 210 and 15 first-magnitude stars, respectively, to minima that are at times actually zero. Mars changes the equivalent of about 8 stars of the first magnitude, Jupiter about 14, Saturn 1.5, Uranus and Neptune practically 0. Hence the total possible change is in the neighborhood of the equivalent of 240 first-magnitude stars, though the actual change is rarely greater than the equivalent of 230 such stars; that is, as simple division will show, a change in the total incoming and, assuming equilibrium, also in the outgoing radiation of 1 part in 300,000,000 is the utmost limit. The percentage change, however, in the outgoing energy, since the earth radiates very nearly as a black body and therefore in proportion to the 4th power of its absolute temperature, is approximately four times the percentage change of this absolute temperature. Hence the planets, through their variations in brightness, can alter the absolute temperature of the earth by only 1 part in 1,200,000,000. But the absolute temperature of the earth as a full radiator, its planetary temperature, is about 485°F., and therefore the above change can seldom exceed 0.000 000 4°F., or, say, one two-millionth of a degree F. at the surface of the earth—surely a negligible amount.

Change in earth's distance from the sun.—The second factor, however, the change of the earth's distance from the sun due to perturbations in its orbit caused by the planets, is, as we shall see, of much greater consequence, though it, too, is practically negligible in amount.

Jupiter changes the distance of the earth from the sun by about 1 part in 20,000; Venus and Mars each by about 1 part in 90,000; and the other planets by amounts so much smaller that their action may, in this case, be neglected. Since the perturbative effects of an inner planet on the course of the earth are more or less opposite

to those due to an outer planet, especially at or near the times of their maxima, it will be sufficiently accurate to assume that the total change in the earth's distance from the sun, due to the combined action of all the planets, seldom is greater than 1 part in 17,000 of its average distance.

But the amount of radiation received by the earth from the sun varies inversely as the square of the distance between them. Hence the above change in this distance causes a change of 1 part in 8,500 of the earth's incident energy, and therefore, as already explained, one-fourth this latter fraction, or 1 part in 34,000, in its black-body absolute temperature of 485°F. Hence perturbations in the earth's path, due to the gravitational actions of the planets, may occasionally alter its temperature as a full radiator by 0.014°F., or the actual surface temperature, under the most favorable circumstances, possibly by as much as 0.02°F. Ordinarily, though perhaps not always, this too, so far as weather and climate are concerned, is a negligible temperature range.

So far as known, these are the only effects planets have on terrestrial weather and terrestrial climate. They are real and definitely calculable even though the one is always negligible and the other at least generally so. They therefore have nothing in common with the astrological or other nonsense that seems usually to be in the minds of those who insist that the planets do greatly influence or even control our weather and our climates.

The moon.—A word or two about the moon may also be interesting in this connection. The light of the full moon is the equivalent of about 128,000 stars of the first magnitude, and therefore by its radiation alone may, as a little calculation will show, change the earth's planetary temperature by 0.0002°F., or the surface temperature by, say, 0.00025°F.

But the moon and the earth rotate about their common center of gravity, a point some 3,000 miles from the center of the earth, and in this way the moon every month changes the earth's distance from the sun by approximately 6,000 miles. This in turn, as one may easily compute, changes the earth's planetary temperature by about 0.015°F., or its surface temperature by about 0.02°F. That is, it changes the surface temperatures through ranges whose maxima are approximately 0.01°F. on either side of the normal.

Both these lunar effects on the earth's temperature run their course once each lunar month, while the stellar effects are of much longer period. The chief stellar effect, being caused by the perturbations due to Jupiter, has a period of about 13 months.

The above, of course, does not exhaust all possible relations between the moon and weather, especially the weather of certain localities. It is known that not only the tides but also many ocean currents are more or less affected by the movements of the moon, and it is held by some earnest workers on this subject that these changes in turn either cause or are accompanied by small but measurable changes in the local weather of certain places. But this tidal effect is another story. It is only hinted at here with the object of guarding against the assumption that, as a scientific subject, it deserves to be dismissed with a "tut, tut" or a "pooh-pooh."

THE THUNDERSTORM AND ITS PHENOMENA.

By W. J. HUMPHREYS, Professor of Meteorological Physics.

[Dated, Weather Bureau, Washington, D. C., July 17, 1914.]

Introduction.—A thunderstorm, as its name implies, is a storm characterized by thunder and lightning, just as a dust storm is one characterized by a great quantity of flying dust. But the dust is never in any sense the cause of the storm that carries it along, nor, so far as known, does either thunder or lightning have any influence on the course—genesis, development, or termination—of even those storms of which they form, in some respects, the most important features. No matter how impressive nor how terrifying these phenomena may be, they never are anything more than mere incidents to or products of the peculiar storms they accompany, as will be made clear by what follows. In short, they are never in any sense either storm-originating or storm-controlling factors.

Origin of thunderstorm electricity.—A knowledge, or at least a good working hypothesis, of how the great amount of electricity incident to thunderstorms is generated, is absolutely essential to their logical explanation; that is, to a clear understanding of the probable interrelations between their many phenomena. Fortunately such an hypothesis, or theory, rather, since it is abundantly supported by observations and by laboratory experiments, is available as a result of work done on this subject in India by Dr. G. C. Simpson (1) of the Indian Meteorological Department.

Dr. Simpson's observations, just referred to, were obtained at Simla, India, at an elevation of about 7,000 feet above sea level, and covered all of the monsoon seasons, that is, roughly, April 15 to September 15, of 1908 and 1909. He also obtained observations of the electrical conditions of the snow at Simla during the winter of 1908-9.

A tipping-bucket rain gage gave an automatic continuous record of the rate and time of rainfall, while a Benndorf (2) self-registering electrometer marked the sign and potential of the charge acquired during each two-minute interval. A second Benndorf electrometer registered the potential gradient near the earth, and a coherer of the type used in radiotelegraphy registered the occurrence of each lightning discharge.

All obvious sources of error were examined and carefully guarded against. Hence it would seem that the conclusions drawn from the thousands of observations given in the memoir are fully justified; and especially so since several independent series of similar observations made at different times, by different people, and at places widely separated, have given confirmatory results in every case. Simpson's records show that—

(1) The electricity brought down by the rain was sometimes positive and sometimes negative.

(2) The total quantity of positive electricity brought down by the rain was 3.2 times greater than the total quantity of negative electricity.

(3) The period during which positively charged rain fell was 2.5 times longer than the period during which negatively charged rain fell.

(4) Treating charged rain as equivalent to a vertical current of electricity, the current densities were generally smaller than 4×10^{-15} amperes per square centimeter; but on a few occasions greater current densities, both positive and negative, were recorded.

(5) Negative currents occurred less frequently than positive currents, and the greater the current density the greater the preponderance of the positive currents.

(6) The charge carried by the rain was generally less than 6 electrostatic units per cubic centimeter of water, but larger charges were occasionally recorded, and in one exceptional storm (May 13, 1908) the negative charge exceeded 19 electrostatic units per cubic centimeter.

(7) As stated in paragraph (3) above, positive electricity was recorded more frequently than negative, but the excess was the less marked the higher the charge on the rain.

(8) With all rates of rainfall positively charged rain occurred more frequently than negatively charged rain, and the relative frequency of positively charged rain increased rapidly with increased rate of rainfall. With rainfall of less than about 1 millimeter in two minutes, positively charged rain occurred twice as often as negatively charged rain, while with greater intensities it occurred 14 times as often.

(9) When the rain was falling at a less rate than about 0.6 millimeter in two minutes, the charge per cubic centimeter of water decreased as the intensity of the rain increased.

(10) With rainfall of greater intensity than about 0.6 millimeter in two minutes the positive charge carried per cubic centimeter of water was independent of the rate of rainfall, while the negative charge carried decreased as the rate of rainfall increased.

(11) During periods of rainfall the potential gradient was more often negative than positive, but there were no clear indications of a relationship between the sign of the charge on the rain and the sign of the potential gradient.

(12) The data do not suggest that the negative electricity occurs more frequently during any particular period of a storm than during any other.

Concerning his observation on the electrification of snow Dr. Simpson says:

As far as can be judged from the few measurements made during the winter of 1908-9 it would appear that:

(1) More positive than negative electricity is brought down by snow in the proportion of about 3.6 to 1.

(2) Positively charged snow falls more often than negatively charged.

(3) The vertical electric currents during snowstorms are on the average larger than during rainfall.

(4) The charge per unit mass of precipitation is larger during snowfall than during rainfall.

While these observations were being secured a number of well-devised experiments were made to determine the electrical effects of each obvious process that takes place in the thunderstorm.

Freezing and thawing, air friction, and other things were tried, but none produced any electrification. Finally, on allowing drops of *distilled* water to fall through a vertical blast of air of sufficient strength to produce some spray, positive and important results were found, showing:

(1) That breaking of drops of water is accompanied by the production of both positive and negative ions.

(2) That three times as many negative ions as positive ions are released.

Now, a strong upward current of air is one of the most conspicuous features of the thunderstorm. It is always evident in the turbulent cauliflower heads of the cumulus cloud, the parent, presumably, of all thunderstorms. Besides, its inference is compelled by the occurrence of hail, a frequent thunderstorm phenomenon, whose formation requires the carrying of raindrops and the growing hailstones repeatedly to cold and therefore high altitudes. And from the existence of hail it is further inferred that an updraft of at least 8 meters per second must often occur within the body of the storm, since, as experiment shows, it requires approximately this velocity to support the larger drops, and even a greater velocity to support the average hailstone.

Experiment also shows that rain can not fall through air of ordinary density whose upward velocity is greater than about 8 meters per second, or itself fall with greater velocity through still air; that in such a current, or with such a velocity, drops large enough, if kept intact, to force their way down, or, through the action of gravity, to attain a greater velocity than 8 meters per second with reference to the air, whether still or in motion, are so blown to pieces that the increased ratio of supporting area to total mass causes the resulting spray to be carried aloft or left behind, together with, of course, all original smaller drops. Clearly, then, the updrafts within a

cumulus cloud frequently must break up at about the same level innumerable drops which, through coalescence, have grown beyond the critical size, and thereby, according to Simpson's experiments, produce electrical separation within the cloud itself. Obviously, under the turmoil of a thunderstorm, its choppy surges and pulses, such drops may be forced through the cycle of union (facilitated by any charges they may carry) and division, of coalescence and disruption, from one to many times, with the formation on each at every disruption, again *according to experiment* of a correspondingly increased electrical charge. The turmoil compels mechanical contact between the drops, whereupon the charges break down the surface tension and insure coalescence. Hence, once started, the electricity of a thunderstorm rapidly grows to a considerable maximum.

After a time the larger drops reach, here and there, places below which the updraft is small—the air can not be rushing up everywhere—and then fall as positively charged rain, because of the processes just explained. The negative electrons in the meantime are carried up into the higher portions of the cumulus, where they unite with the cloud particles and thereby facilitate their coalescence into negatively charged drops. Hence, the heavy rain of a thunderstorm should be positively charged, as it almost always is, and the gentler portions negatively charged which very frequently is the case.

Such in brief is Dr. Simpson's theory of the origin of the electricity in thunderstorms, a theory that fully accounts for the facts of observation and in turn is itself abundantly supported by laboratory tests and simulative experiments.

If this theory is correct, and it seems well founded, it must follow that the one essential to the formation of the giant cumulus cloud, namely, the rapid uprush of moist air, is also the one essential to the generation of the electricity of thunderstorms. Hence the reason why lightning seldom if ever occurs except in connection with a cumulus cloud is understandable and obvious. It is simply because the only process that can produce the one is also the process that is necessary and sufficient for the production of the other.

The violent motions of cumulus clouds.—From observations, and from the graphic descriptions of the few balloonists who have experienced the trying ordeal of passing through the heart of a thunderstorm, it is known that there is violent vertical motion and much turbulence in the middle of a large cumulus cloud, a fact which so far as it relates to the theory alone of the thunderstorm, it would be sufficient to accept without inquiring into its cause. However, to render the discussion more nearly complete, it perhaps is worth while, since it is a mooted question, to inquire what the probable cause of the violent motions in large cumulus clouds really is—motions which, in the magnitude of their vertical components and degree of turmoil, are never exhibited by clouds of any other kind nor met with elsewhere by either manned, sounding, or pilot balloons.

It has been shown by von Bezold (**3**) that sudden condensation from a state of supersaturation, and also sudden congelation of undercooled cloud droplets, would, as a result of the heat thus liberated, cause an equally sudden expansion of the atmosphere, and thereby turbulent motions analogous to those observed in large cumuli. However, as von Bezold himself points out, it is not evident how either the condensation or the freezing could suddenly take place throughout a cloud volume great enough to produce the observed effects. Besides, these eruptive turmoils, whatever their genesis, undoubtedly originate and run their course in regions already filled with cloud particles in the presence of which no appreciable degree of supersaturation can occur. Hence the rapid uprush and the violent turbulence in question obviously must have some other cause; and this we shall find in the difference between the actual temperature gradient of the surrounding atmosphere and the adiabatic temperature gradient of the saturated air within the cloud itself.

Consider a warm summer afternoon, temperature 30° C., say, and assume the dew point to be 15° C. Now, the adiabatic decrease of temperature of nonsaturated air is about 1° C. per 100 meters change in elevation, and therefore, under the assumed conditions, vertical convection of the surface air causes condensation to begin at an elevation of approximately 1.5 kilometers. From this level, however, so long as the cloud particles are carried up with the rising air, the rate of temperature decrease, for at least a couple of kilometers, is much less—at first about one-half the previous rate. After a considerable rise above the level of initial condensation, half a kilometer, say, the raindrops have so increased in size as to lag behind the upward current and even to drop out, while, at the same time, the amount of moisture condensed per degree fall of temperature grows rapidly less. Hence, for both reasons—because the heat of the condensed water is no longer available to the air from which it was condensed, the drops having been left behind, and because but little latent heat is to be had from further condensation, there being but little water vapor left—the rate of temperature decrease again approaches the adiabatic gradient of dry air, or 1° C. per 100 meters change of elevation.

Obviously, then, for some distance above the level at which condensation begins to set free its latent heat, the temperature of the rising mass of moist air departs farther and farther from the temperature of the surrounding atmosphere at the same level, and therefore its buoyancy for a time as steadily increases. But, of course, as explained above, this increase of buoyancy does not continue to any great altitude.

In the lower atmosphere continuous and progressive convection builds up the adiabatic gradient so gradually that no great difference between the temperature of the rising column and that of the adjacent atmosphere is anywhere possible. Hence, under ordinary conditions, the uprush in this region is never violent. But whenever the vertical movement of the air brings about a considerable condensation it follows, as above explained, that there is likely to be an increase in its buoyancy, and hence a more or less rapid upward movement of the central portion, like air up a heated chimney, and for the same reason, together with, because of viscosity, a rolling and turbulent motion of the sides, of the type so often seen in towering cumulus clouds. Obviously, too, the uprushing column of air must ascend somewhat beyond its point of equilibrium, and then, because slightly undercooled, correspondingly drop back.

Figure 1, based upon approximately average conditions, illustrates the points just explained. The elevation is in kilometers and the temperature in degrees centigrade.

AB is the approximate temperature gradient for nonsaturated air, about 1° C. per 100 meters change in elevation. *GCKDEF* is the supposed temperature gradient before convection begins, or a decrease, in accordance with observations, of 6° C., approximately, per kilometer increase of elevation, except near the surface, where the temperature decrease, before convection has begun, ordinarily is less rapid.

As convection sets in, the temperature decrease near the surface soon approximates the adiabatic gradient for dry air, and this condition extends gradually to greater altitudes, till, in the assumed case, condensation begins at the level C, or where the temperature is 15°C. Here the temperature decrease, under the assumed conditions, suddenly changes from 10°C. per kilometer increase of elevation to rather less than half that amount, but slowly increases with increase of altitude and consequent decrease of temperature. At some level, as L, the temperature difference between the rising and the adjacent air is a maximum. At D the temperature of the rising air is the same as that of the air adjacent, but its momentum presumably carries it on to some such level as H. Within the rising column, then, the temperature gradient is

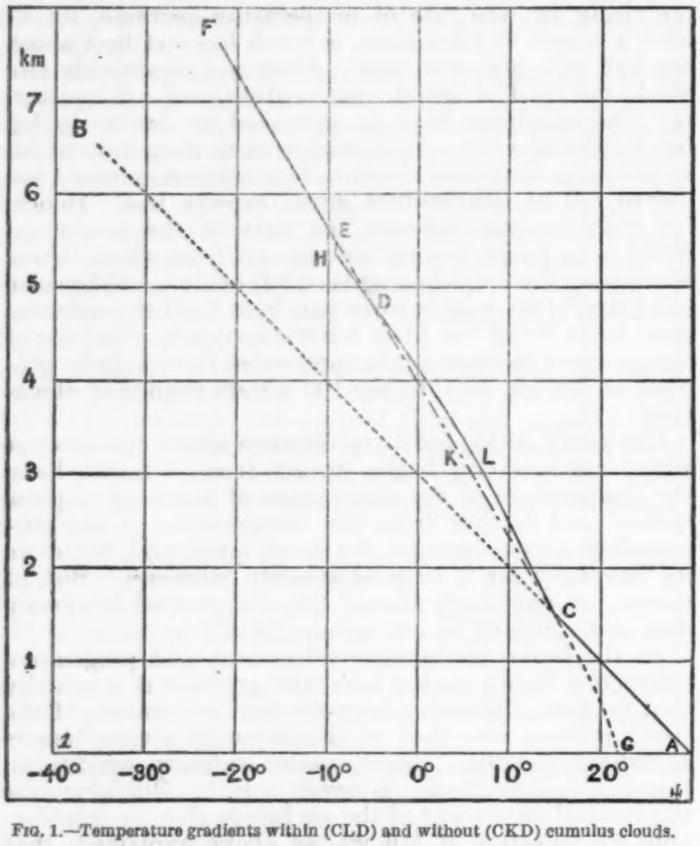

FIG. 1.—Temperature gradients within (CLD) and without (CKD) cumulus clouds.

approximately given by the curve $ACLDHE$, while the temperature gradient of the surrounding air is given by the curve $ACKDEF$.

The cause, therefore, of the violent uprush and turbulent condition within large cumulus clouds is, presumably, the difference between the temperature of the inner or warmer portions of the cloud itself and that of the surrounding atmosphere at the same level, as indicated by their respective temperature gradients CLD and CKD. Clearly, too, while some air must flow into the condensation column all along its length, the greatest pressure difference, and, therefore, the greatest inflow, obviously is at its base. After the rain has set in, however, this basal inflow is from immediately in front of the storm, and necessarily so, as will be explained later.

Convectional instability.—Rapid vertical convection of humid air, as we have seen, is essential to the production of the cumulus cloud and, therefore, to the generation of the thunderstorm. Hence it is essential to consider the conditions under which the vertical temperature gradient necessary to this convection can be established. These are:

1. Strong surface heating, especially in regions of light winds; a frequent occurrence.

The condition that the winds be light is not essential, or, perhaps, even favorable to the genesis of all thunderstorms—only the local or heat variety, and favorable to these simply because heavy winds tend to prevent the formation of isolated rising columns of air, the progenitors of this particular type of storm.

2. The overrunning of one layer of air by another at a temperature sufficiently lower to induce convection, wellnigh the sole cause of ocean thunderstorms and also of frequent occurrence on land.

3. The underrunning and consequent uplift of a saturated layer of air by a denser layer; a frequent occurrence to a greater or less extent and, presumably, therefore at least an occasional one of sufficient magnitude to produce a thunderstorm.

Here the underrunning air lifts both the saturated layer and the superincumbent unsaturated layer, and thereby forces each to cool adiabatically. But as both layers are lifted equally while, because of the latent heat of condensation, the saturated layer cools much slower than the dry, it follows that a sufficient mechanical lift of a saturated layer of air would establish between it and the nonsaturated layer above a superadiabatic temperature gradient and thereby produce local convection, cumulus clouds, and, perhaps, a thunderstorm.

Periodic recurrence of thunderstorms.—While thunderstorms may occur at any hour of any day they nevertheless have three distinct periods of maximum occurrence: *a*, daily, *b*, yearly, and *c*, irregularly cyclic. Each maximum depends upon the simple facts that the more humid the air and the more rapid the local vertical convections the more frequent and also the more intense the thunderstorms, for the obvious reason that it is rapid vertical convection of humid air that produces them.

Daily land period.—Vertical convection of the atmosphere over land areas is most pronounced when the surface is most heated; that is, during afternoons. Hence the hours of maximum frequency of inland or continental thunderstorms are, in most places, 2 to 4 p. m.

Daily ocean period.—Because of evaporation and of the high specific heat of water the surface temperature of the ocean increases but little during the day, and because of convection it decreases but slightly at night. Indeed, the diurnal temperature range of the ocean surface usually is but a small fraction of one degree C., while that of the atmosphere at from 500 to 1,000 meters elevation is several fold as great (4). Hence those temperature gradients over the ocean that are favorable to rapid vertical convection are most frequent during the early morning hours, and, therefore, the maximum of ocean thunderstorms usually occurs between midnight and 4 a. m.

Yearly land period.—Just as inland thunderstorms are most frequent during the hottest hours of the day, so too, and for the same reason, they are, in general, most frequent over the land during the hottest months of the year, or, rather, during those months when the amount of surface heating and, therefore, the vertical temperature gradient is a maximum.

Hence, in middle latitudes, where there are no late spring snows to hold back the temperatures, the month of maximum frequency often is June. In higher latitudes, where the strong surface heating is more or less delayed, the maximum occurs in July or even August.

Yearly ocean period.—Over the oceans, on the other hand, temperature gradients favorable to the genesis of

thunderstorms, and, therefore, the storms themselves, occur most frequently during the winter and least frequently during the summer. This is because the temperature of the air at some distance above the surface, being largely what it was when it left the windward continent, greatly changes from season to season while that of the water, and, of course, the air in contact with it, changes but little through the year. That is, over the oceans the average decrease of temperature with increase of elevation obviously is least and, therefore, thunderstorms fewest in summer, and greatest, with such storms most numerous, in winter.

Cyclic land period.—Since thunderstorms are accompanied by rain and since over land they are most numerous during summer, it would appear that they must occur most frequently either in warm or in wet years and least frequently in cold or in dry years. Further, if it should happen, as it actually does, that, for the earth as a whole, warm years are also wet years and dry years cold years, it would appear logically certain that, for the entire world, the maximum number of thunderstorms must belong to the years that are wet and warm and the minimum to those that are cold and dry.

A complete statistical examination of these statements is not possible, owing to the fact that meteorological data are available for only portions of the earth's surface and not for the whole of it. Nevertheless, well-nigh conclusive data do exist. The annual rainfall, for instance, to the leeward of a large body of water obviously must bear the same relation to the annual average windward temperature that the total annual precipitation over the entire world does to the annual average world temperature. In each case the amount of evaporation or amount of water vapor taken into the atmosphere, and, therefore, the amount of subsequent precipitation, clearly must increase and decrease with the temperature. An excellent test and complete support of this deduction is furnished by figure 2, in which the full line represents the smoothed annual European precipitation (5), and the dotted line smoothed annual average eastern American temperatures.

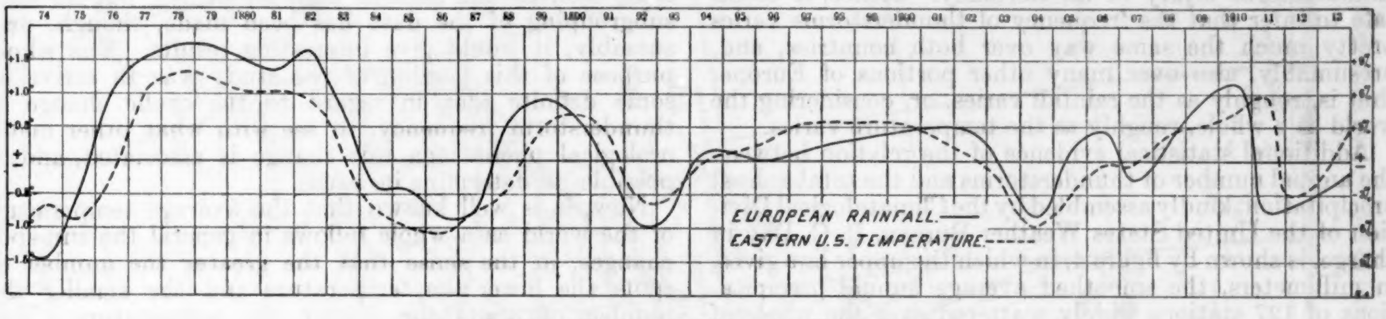

FIG. 2.—Relation of European rainfall to eastern U. S. temperature.

Beyond a reasonable doubt, therefore, for the world as a whole, warm years are wet and cold ones are dry. Hence, as above stated, it is practically certain that the maxima of thunderstorms occur during years that are wet, or warm, if we prefer, for the two are synchronous, and the minima during years that are dry, or cold. A partial and, so far as it goes, a confirmatory statistical test of this conclusion is given by figure 3. The lower group of curves is based on an exhaustive study by Dr. von Gulik (6) of thunderstorms and lightning injuries in Holland. The continuous zigzag line gives the actual annual number of thunderstorm days and the continuous curved line the same numbers smoothed. The broken lines give, respectively, the actual and the smoothed values of the annual average precipitation. The upper curve represents the variations in the smoothed number of destructive thunderstorms (7) (number of thunderstorm days not readily available) in Germany.

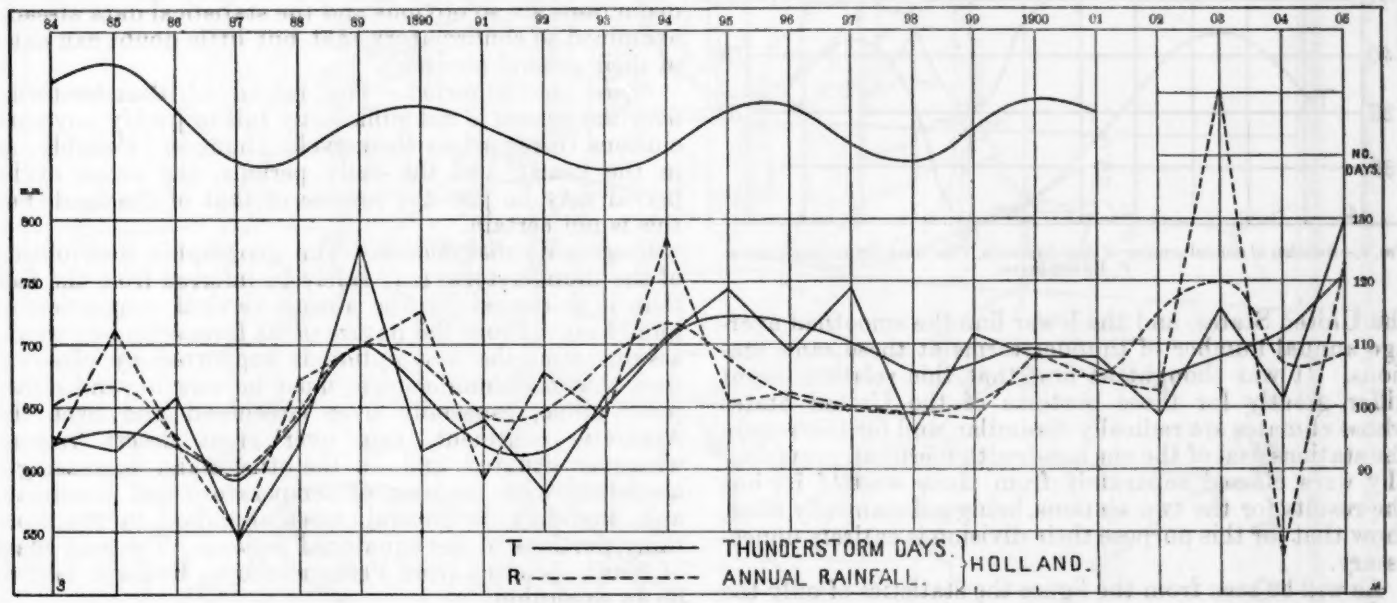

FIG. 3.—Relation of annual number of thunderstorm days to total annual precipitation—Holland. The uppermost, wavy curve shows the variation in the smoothed numbers of destructive thunderstorms in Germany.

The original data on which this last curve is based indicate a continuous and rapid increase of thunderstorm destructiveness. Presumably, however, this feature is real only to the extent that the country has become more densely populated and more thickly studded with destructible property. At any rate, this element has been omitted from the curve and only the variation factor retained.

It will be noted that the curve of thunderstorm frequency for all Holland closely parallels the curve of thunderstorm injury in all Germany. Hence, it seems safe to infer that the frequency of thunderstorms varies pretty much the same way over both countries, and, presumably, also over many other portions of Europe; that is, roughly as the rainfall varies, or, considering the world as a whole, roughly as the temperature varies.

Additional statistical evidence of the relation between the annual number of thunderstorms and the total annual precipitation, kindly assembled by the Climatological Division of the United States Weather Bureau, P. C. Day in charge, is shown by figure 4, in which the upper line gives, in millimeters, the smoothed average annual precipitations of 127 stations widely scattered over the whole of

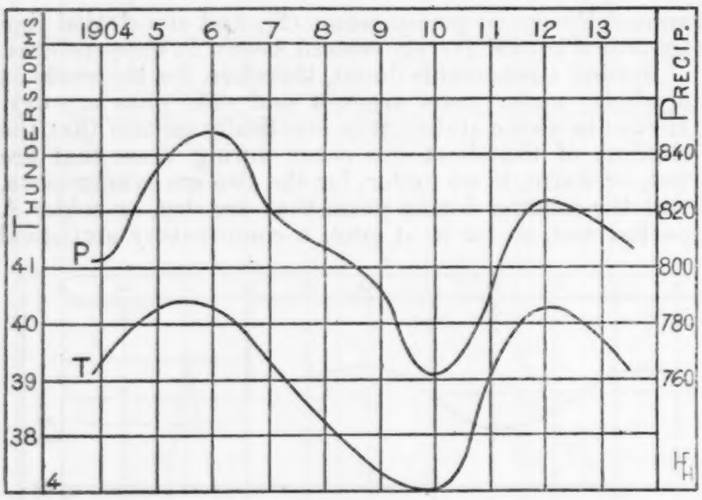

FIG. 4.—Relation of annual number of thunderstorms, T, to total annual precipitation, P, United States.

the United States, and the lower line the smoothed average annual number of thunderstorms at these same stations. It was thought at first that this relation might differ greatly for those portions of the United States whose climates are radically dissimilar, and for this reason the stations east of the one hundredth meridian provisionally were classed separately from those west of it; but the results for the two sections, being substantially alike, show that for this purpose their division is entirely unnecessary.

As will be seen from the figure the statistics of only the past 10 years have been used. This is because the annual number of such storms reported rapidly decreases from 1904 back to about 1890. Indeed, the annual number of thunderstorms reported per station during the past 10 years is almost double the annual number per station (practically the same stations) from 1880 to 1890. The transition from the smaller to the larger number was due in great measure, doubtless, to an alteration in station regulations that changed the official definition of a thunderstorm from "thunder *with* rain" to "thunder *with* or *without* rain." This, however, does not account for the fact that from 1890 to 1904 the average annual number of thunderstorms reported per station increased, at a nearly constant rate, almost 100 per cent. Either the storms did so increase, which seems improbable, or else there was, on the average, an increase of attention given to this particular phenomenon. At any rate, so continuous and so great an increase in the average number of thunderstorms can hardly be accepted without abundant confirmation, and for this reason the earlier thunderstorm records provisionally have been rejected.

Obviously a much closer relation between the number of thunderstorms and total precipitation would hold for some months and seasons than for others, but no such subgrouping of the data has been made, though, presumably, it would give interesting results. The whole purpose of this portion of the study was to arrive at some definite idea in regard to the cyclic change of thunderstorm frequency, to see with what other meteorological phenomena this change is associated, and, if possible, to determine its cause.

Now, it is well known that the average temperature of the world as a whole follows in general the sun-spot changes, in the sense that the greater the number of spots the lower the temperature and the smaller the number of spots the higher the temperature. This regular relation, however, often is greatly modified (**8**) by the presence in the high atmosphere of volcanic dust, one invariable effect of which is a lower average temperature. Hence, the warm and the cold periods are irregularly cyclic, and also irregular in intensity. Hence, also the annual amount of precipitation, the frequency of thunderstorms, and many other phenomena must perforce undergo exactly the same irregular cyclic variation.

As already stated the statistical evidence bearing on these conclusions neither is nor can be complete, but the deductions are so obvious and the statistical data already examined so confirmatory that but little doubt can exist of their general accuracy.

Cyclic ocean period.—The record of thunderstorms over the oceans is not sufficiently full to justify any conclusions in regard to their cyclic changes. Possibly, as in the yearly and the daily periods, the ocean cyclic period may be just the reverse of that of the land, but this is not certain.

Geographic distribution.—The geographic distribution of the thunderstorm may safely be inferred from the fact that it is caused by the strong vertical convection of humid air. From the nature of its formation one would assume, and the assumption is supported by observation, that the thunderstorm must be rare beyond either polar circle, especially over Greenland and over the Antarctic continent, rare over great desert regions wherever situated, and, on the other hand, increasingly abundant with increase of temperature and humidity, and, therefore, in general, most abundant in the more rainy portions of the equatorial regions. The east coast of South America from Pernambuco to Bahia is said to be an exception.

Pressure and temperature distribution.—In illustrating the occurrence of thunderstorms with reference to the disposition of isobars and isotherms, or the distribution of atmospheric pressure and temperature, typical weather maps of the United States,[1] figures 5–19, have been used, not because the thunderstorms of this country are different in any essential particular from those of other countries, but chiefly as a matter of convenience in making the drawings. To facilitate their study each of the several types discussed is illustrated with three consecutive maps. The first shows the 12-hour antecedent

[1] The author wishes to acknowledge the courteous cooperation of the Forecast Division, U. S. Weather Bureau, in selecting maps typical of thunderstorm conditions in the United States.

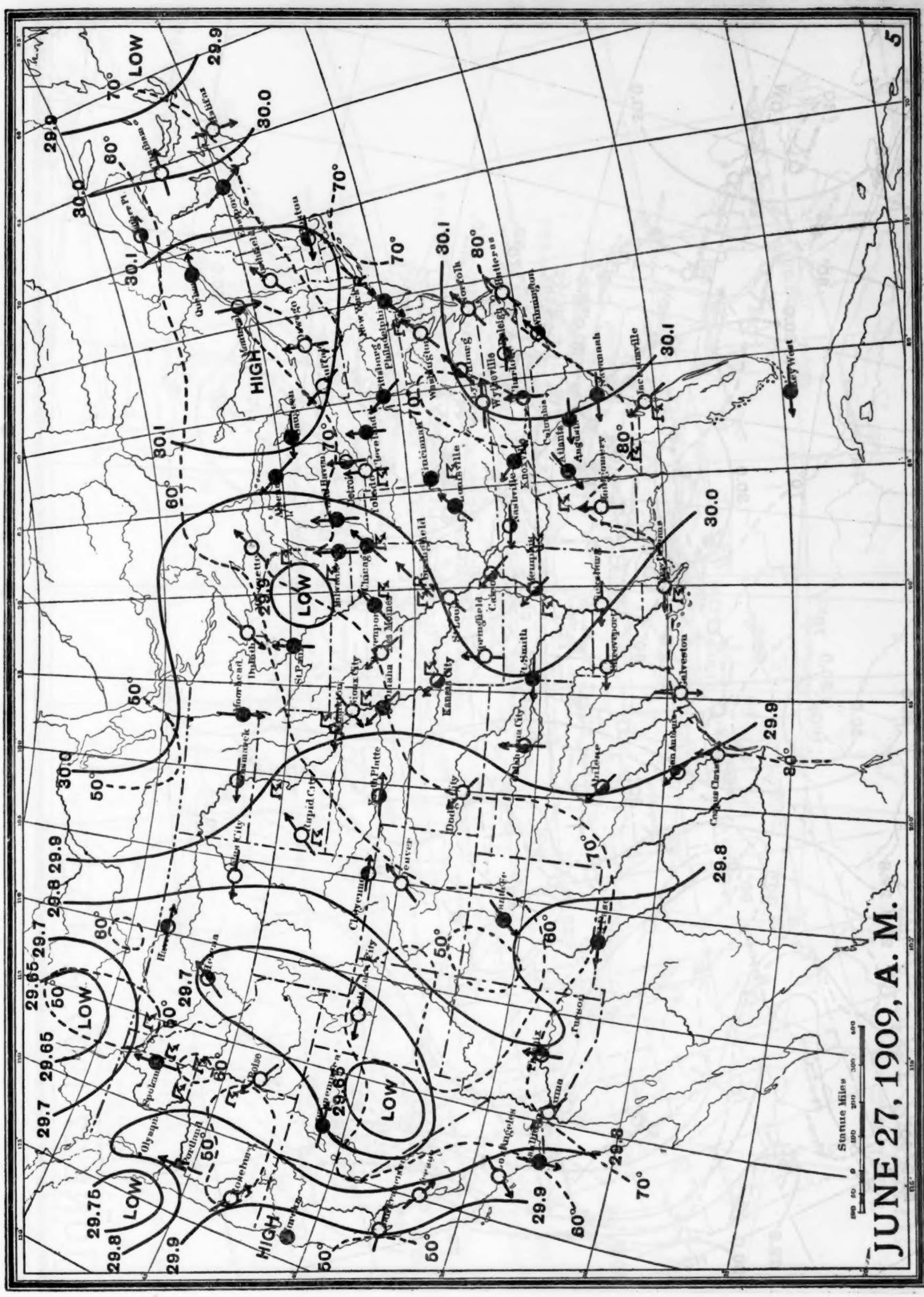

FIG. 5.—Weather Map, 8 a. m., June 27, 1909, typical of conditions at beginning of "heat" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⩍ thunderstorm.

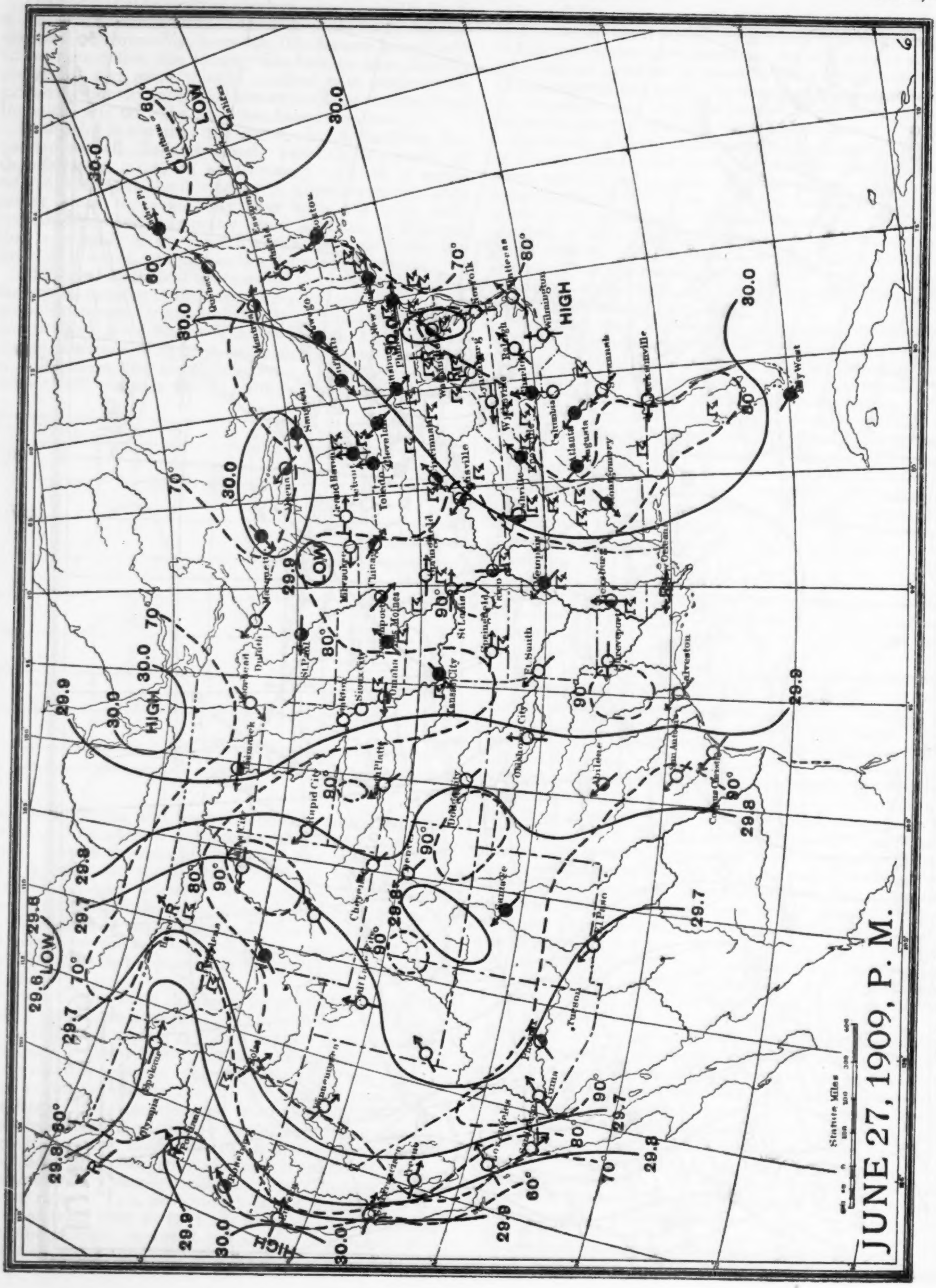

FIG. 6.—Weather Map, 8 p. m., June 27, 1909, typical of "heat" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⊠ thunderstorms.

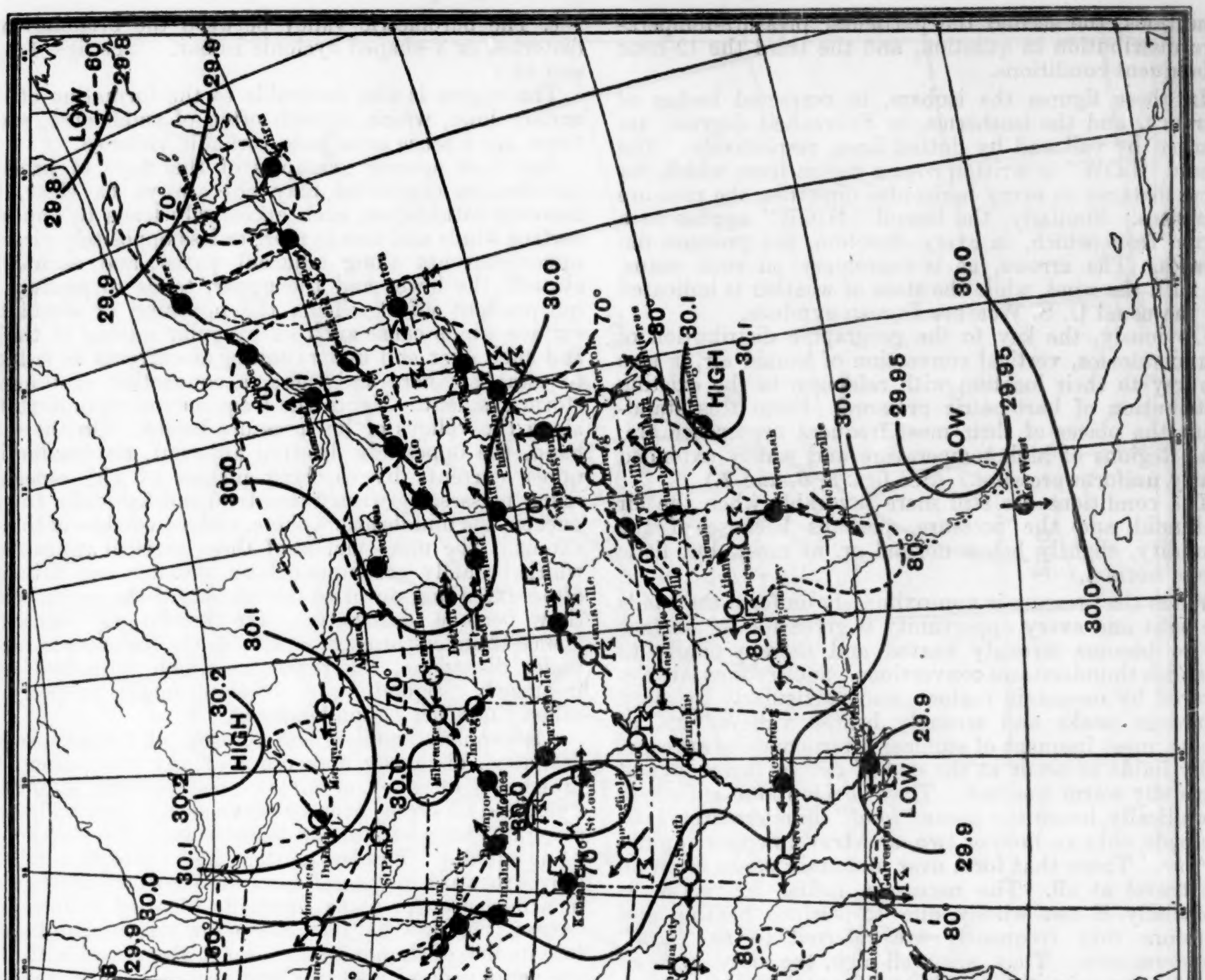

FIG. 7.—Weather Map, 8 a. m., June 28, 1909, typical of conditions at decline of "heat" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; T thunderstorm.

conditions, the second the particular pressure-temperature distribution in question, and the third the 12-hour subsequent conditions.

In these figures the isobars, in corrected inches of mercury, and the isotherms, in Fahrenheit degrees, are marked by full and by dotted lines, respectively. The legend "LOW" is written over a region from which, for some distance in every horizontal direction, the pressure increases. Similarly, the legend "HIGH" applies to a region from which, in every direction, the pressure decreases. The arrows, as is customary on such maps, fly with the wind, while the state of weather is indicated by the usual U. S. Weather Bureau symbols.

Obviously, the key to the geographic distribution of thunderstorms, vertical convection of humid air, is also the key to their location with reference to the existing distribution of barometric pressure. From this standpoint the places of their most frequent occurrence are:

a. Regions of high temperature and widely extended nearly uniform pressure. (See figs. 5, *6*, and 7.)

The conditions are still more favorable when the air is humid and the pressure, perhaps because of the humidity, slightly below normal or, at most, but little above normal.

When the pressure is approximately uniform the winds are light and every opportunity is given for the surface air to become strongly heated and thereby finally to establish thunderstorm convections. Such storms, always favored by mountain regions, and particularly by steep mountain peaks and strongly heated valleys, are, of course, most frequent of summer afternoons and are especially liable to occur at the end of two or three days of unusually warm weather. They develop here and there sporadically, hence the name "*local*" thunderstorm; last, as a rule, only an hour or two, and travel neither rapidly nor far. Those that form over mountain peaks often do not travel at all. The necessary initial convection is essentially, if not wholly, due to surface heating and therefore they frequently are referred to as "*heat*" thunderstorms. They are well-nigh the only type of thunderstorm in the tropics, and, perhaps, the most common type in the warmer portions of the temperate zones.

b. The southeast quadrant (Southern Hemisphere, northeast), or, less frequently, the southwest (Southern Hemisphere, northwest), of a regularly formed low, or typical cyclonic storm. (See figs. 8, *9*, and 10.)

In this case the temperature gradient essential to a rapid vertical convection is not produced chiefly by local surface heating, as it is during the genesis of "heat" thunderstorms, but, in great measure, results from the more or less crossed directions of the under and over currents of air. The surface air of the quadrant in question normally flows from lower and warmer latitudes, while with increasing altitude the winds come more and more nearly from the west, or even northwest. This crossing of the air currents, then, the lower from warmer sections and the upper from regions not so much warmer—possibly even colder—progressively increases the vertical temperature gradient, or rate of temperature decrease with increase of altitude, and therefore may frequently be, and doubtless often finally is, the determining cause of a rapid vertical convection and the formation of a thunderstorm.

This particular type of thunderstorm, commonly known as the "*cyclonic*" thunderstorm, is almost wholly confined to the temperate and higher zones, for the simple reason that the well-defined cyclone, essential to its creation, seldom occurs in tropical or equatorial regions.

c. The barometric valley between the branches of a distorted or V-shaped cyclonic isobar. (See figs. 11, *12*, and 13.)

This region is also favorable to the formation of secondary lows, which, though often of small area, sometimes are intense even unto tornadic violence.

Just how specific examples of this type of pressure distribution originated may not always be clear, but however established, each necessarily leads to opposing surface winds and also to more or less oppositely directed upper currents along adjacent paths; and each wind system, the lower and the upper, tends to produce an independent effect. Thus the opposing or conflicting surface winds cause such an irregular mixing of the air and such over and under running of currents as is likely to establish, here and there, a convection or thunderstorm gradient. Hence the frequency of thunderstorms along the valleys of low-pressure basins. On the other hand, the oppositely directed adjacent, not conflicting, upper currents by catching masses of air, especially rising masses, between them tend mechanically to produce, in the middle atmosphere, violent vortices of limited extent. The more violent of these vertical atmospheric whirls, usually accompanied by thunder and rain and often extending down to the surface of the earth, where they become destructive, are known as tornadoes. Hence thunderstorms generated in the barometric region under discussion, the region in which tornadoes most frequently originate and develop, might properly be called "*tornadic*" thunderstorms.

Atmospheric conflicts and turmoil, of the nature just described, obviously may occur at any place along the protrusion, or valley, of the low-pressure basin, and therefore often do occur, even simultaneously, here and there, along its entire length, and together form the well-known "line squall." Besides, as the whole cyclonic condition moves forward in general from west to east, maintaining, in a measure, for many hours its identity of form and nature, it follows that its valley of low pressure, and therefore its line of thunderstorms, must also travel with it in the same general direction and with approximately the same velocity.

A line or row of thunderstorms—a "line squall"—as observations show, always moves across its own axis, not necessarily at right angles, but nevertheless across and not parallel to it, nor even approximately so. The chief reason for this is not the axial direction of the low-pressure valley which, indeed, though usually running south, may have any orientation from the parent basin, but rather the fact that the valley itself, together with its accompanying thunderstorm conditions, travels across and not along its own direction.

In this connection it is also worth noting that the temperature distribution in the wake of a thunderstorm renders the occurrence of an immediate successor improbable, as will be explained later. Hence while a considerable number of thunderstorms may and often do travel abreast they can never follow each other closely in file.

d. The region covered by a low-pressure trough between adjacent high-pressure areas. (Figs. 14, *15*, and 16.)

Along the adjacent borders of two neighboring anticyclones—that is, along the barometric trough between them—the surface winds from one side are more or less directly opposed to those from the other. Hence, because of the overrunning, as explained under *c*, and the resulting temperature gradients, this also is a region of frequent thunderstorms. Here, too, a number of more or less independent storms may exist simultaneously along the same line, and advance abreast for great distances across the country.

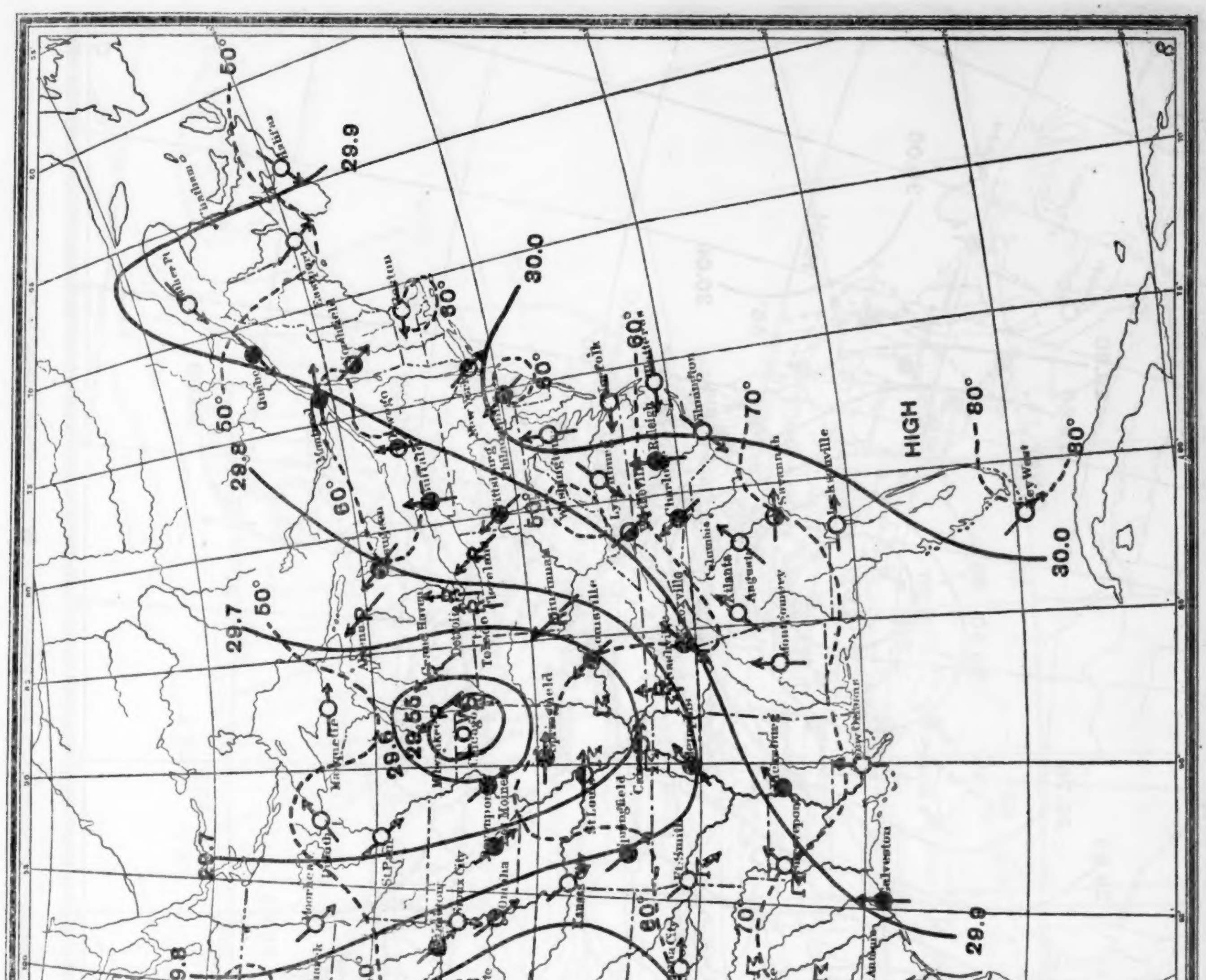

FIG. 8.—Weather Map, 8 a. m., June 4, 1907, typical of conditions at beginning of "cyclonic" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⊠ thunderstorm.

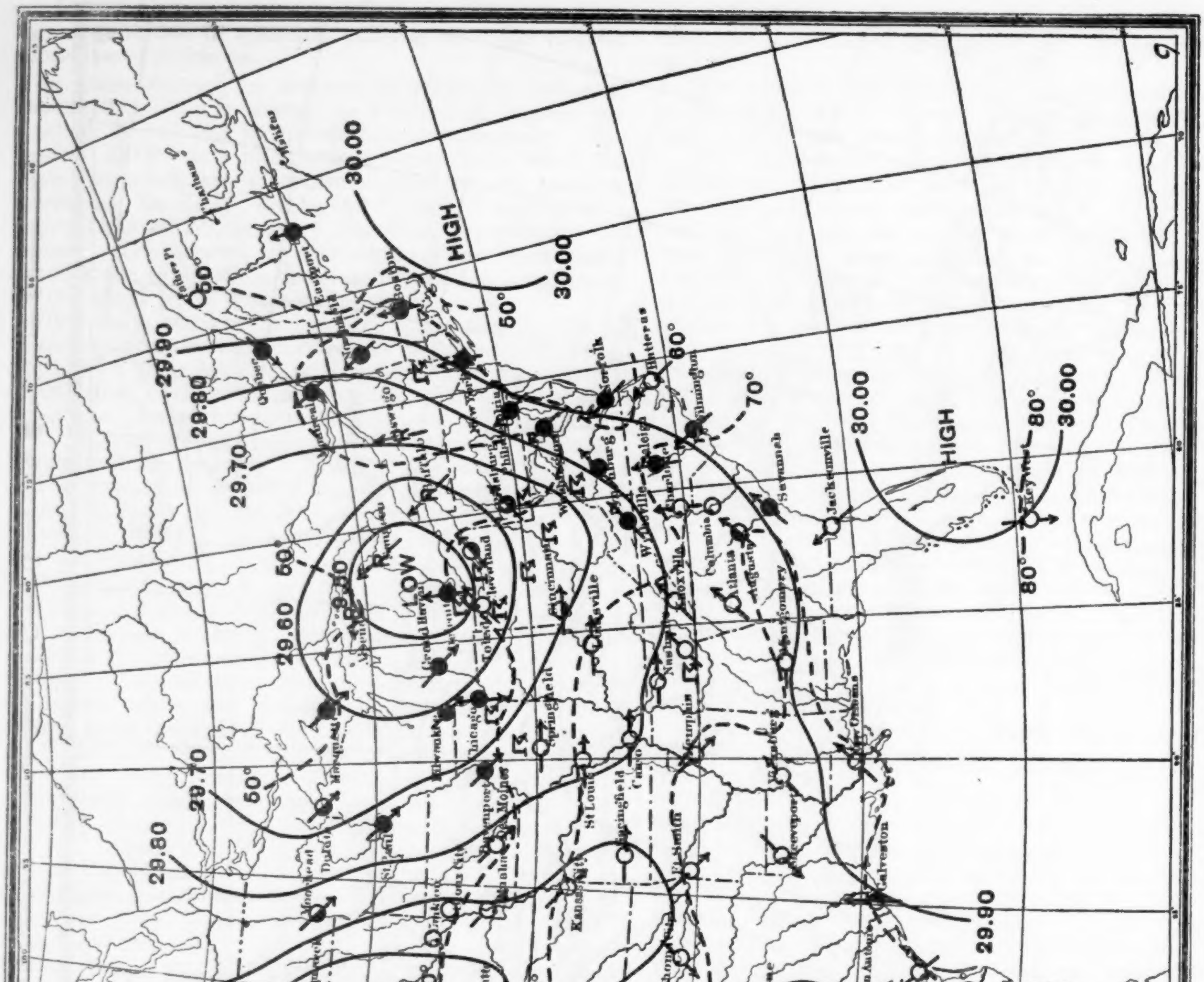

FIG. 9.—Weather Map, 8 p. m., June 4, 1907, typical of "cyclonic" thunderstorms. ○ clear; ◑ partly cloudy; ● cloudy; R rain; ⊼ thunderstorm.

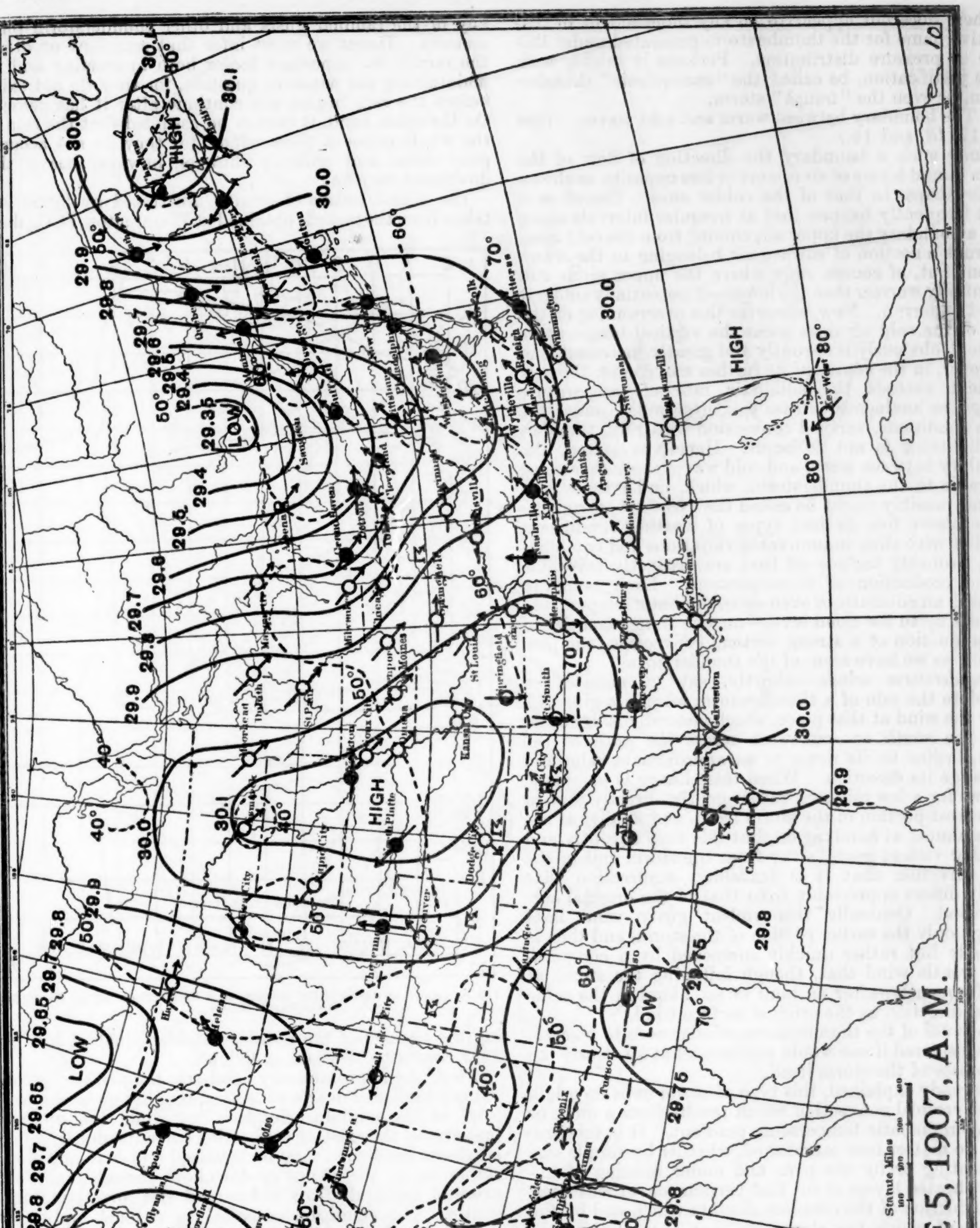

FIG. 10.—Weather Map, 8 a. m., June 5, 1907, types of conditions at decline of "cyclonic" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; T thunderstorm.

There does not appear to be any independent or distinctive name for the thunderstorm generated under this type of pressure distribution. Perhaps it might, with some justification, be called the "*anticyclonic*" thunderstorm, or even the "*trough*" storm.

e. The boundary between warm and cold waves. (See figs. 17, *18*, and 19.)

Along such a boundary the direction of flow of the warm humid layers of air is more or less opposite, as shown on the maps, to that of the colder ones. Therefore it must frequently happen that at irregular intervals along such a boundary the upper air, coming from the cold area, overruns a section of surface air belonging to the warm region; but, of course, only where the upper air is still potentially warmer than the lower—if potentially colder it would underrun. Now, wherever this overrunning on the part of the cold air does occur the vertical temperature gradient obviously is abruptly and greatly increased, and wherever, in the course of its further movement, the new gradient exceeds the adiabatic rate of temperature change, as analogous to case *b*, it often must, under the given conditions, vertical convection with rain, thunder, and lightning is apt to occur. Hence, as stated, the boundary between warm and cold waves is another place favorable to the thunderstorm, which, under these conditions, possibly might be called the "*border*" storm.

The above five distinct types of weather conditions, together with their innumerable variations and combinations, probably include all that are distinctly favorable to the production of thunderstorms. Each tends to establish an adiabatic or even superadiabatic temperature gradient up to the cloud level—the one thing essential to the production of a strong vertical convection, the progenitor, as we have seen, of the thunderstorm.

Thunderstorm winds.—Shortly, say 20 minutes or so, before the rain of a thunderstorm reaches a given locality the wind at that place, which generally is light and from the south or southwest across the path of the storm, begins to die down to an approximate calm and to change its direction. When this change is complete, it blows for a few minutes, rather gently, directly toward the nearest portion of the storm front, and finally, as the rain is almost at hand, again, but this time abruptly and in rather violent gusts, away from the storm and in the same direction that it is traveling, a direction that usually differs appreciably from that of the original surface wind. Generally this violent gusty wind lasts through only the earlier portion of the storm, and then is gradually but rather quickly succeeded by a comparatively gentle wind that, though following the storm at first, frequently, after an hour or so, blows in the same general direction as the original surface wind.

The cause of the thunderstorm winds needs to be carefully considered if one would understand at all clearly the mechanism of the storm itself.

As already explained, this type of storm owes its origin to that vertical convection which results from a more or less superadiabatic temperature gradient. It is this gradient, no matter how established, whether by simple surface heating or by the over and under running of unequally heated layers of air, that permits, or rather forces, the production of the cumulus cloud in which and by the motions of which the electricity that characterizes the storm in question is generated.

Nevertheless, as everyone knows, the passage of a cumulus cloud overhead, however large, so long as no rain is falling from it, does not greatly affect the direction and magnitude of the surface wind—does not bring on any of the familiar gusts and other thunderstorm phenomena. Hence we must infer that somehow or other the rain is an important factor both in starting and in maintaining the winds in question, for they do not exist before the rain begins nor continue after it has ceased. On the other hand, it cannot be assumed that the rain is the whole cause of these winds, for they do not accompany other and ordinary showers, however heavy the downpour may be.

The actual course of events, illustrated by figure 20, taken from the records obtained at Washington, D. C., during the passage of the notable thunder squall of July 30, 1913, seems to be about as follows:

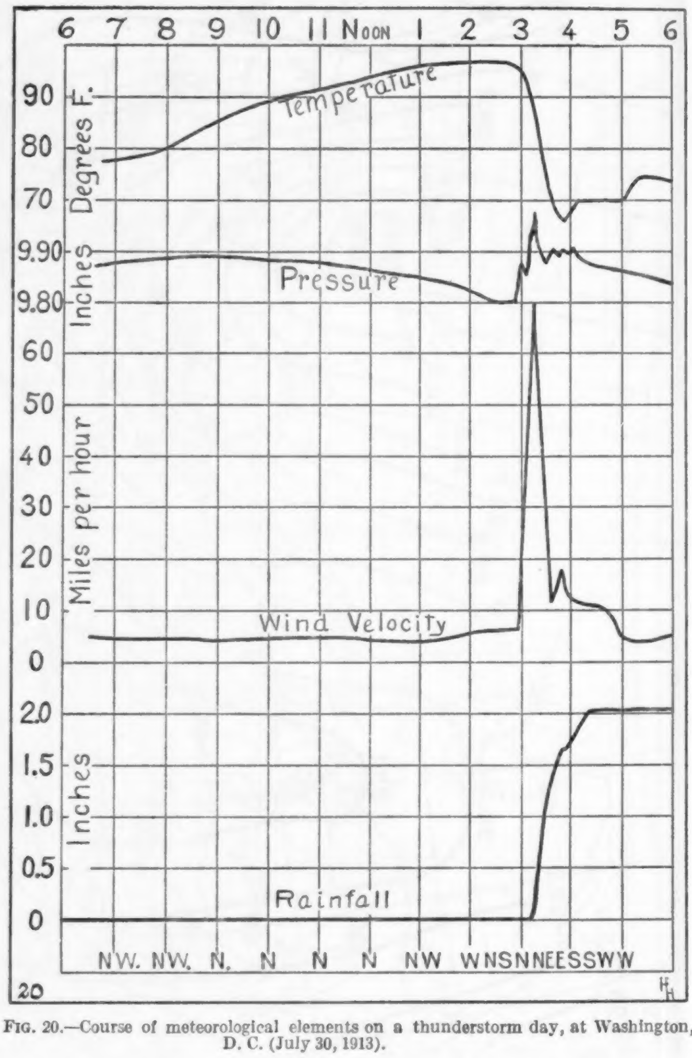

FIG. 20.—Course of meteorological elements on a thunderstorm day, at Washington, D. C. (July 30, 1913).

First. An approximately adiabatic temperature gradient is established over a wide area, roughly up to the base level of the cumulus clouds. But while the uprising branches of the existing convection currents, due to superadiabatic gradients, may be localized and here and there rather rapid, the return or downflow, though really the cause of the updraft, is widespread and correspondingly gentle. The condition essential to a local and rapid downflow—that is, a local decided cooling at a high altitude—does not exist, and therefore the counterpart to the upward currents is nowhere conspicuous.

Second. After a time, as a result of strong convection in a cumulus cloud, rain is formed at a considerable altitude where, of course, the air is quite cold, in fact so cold

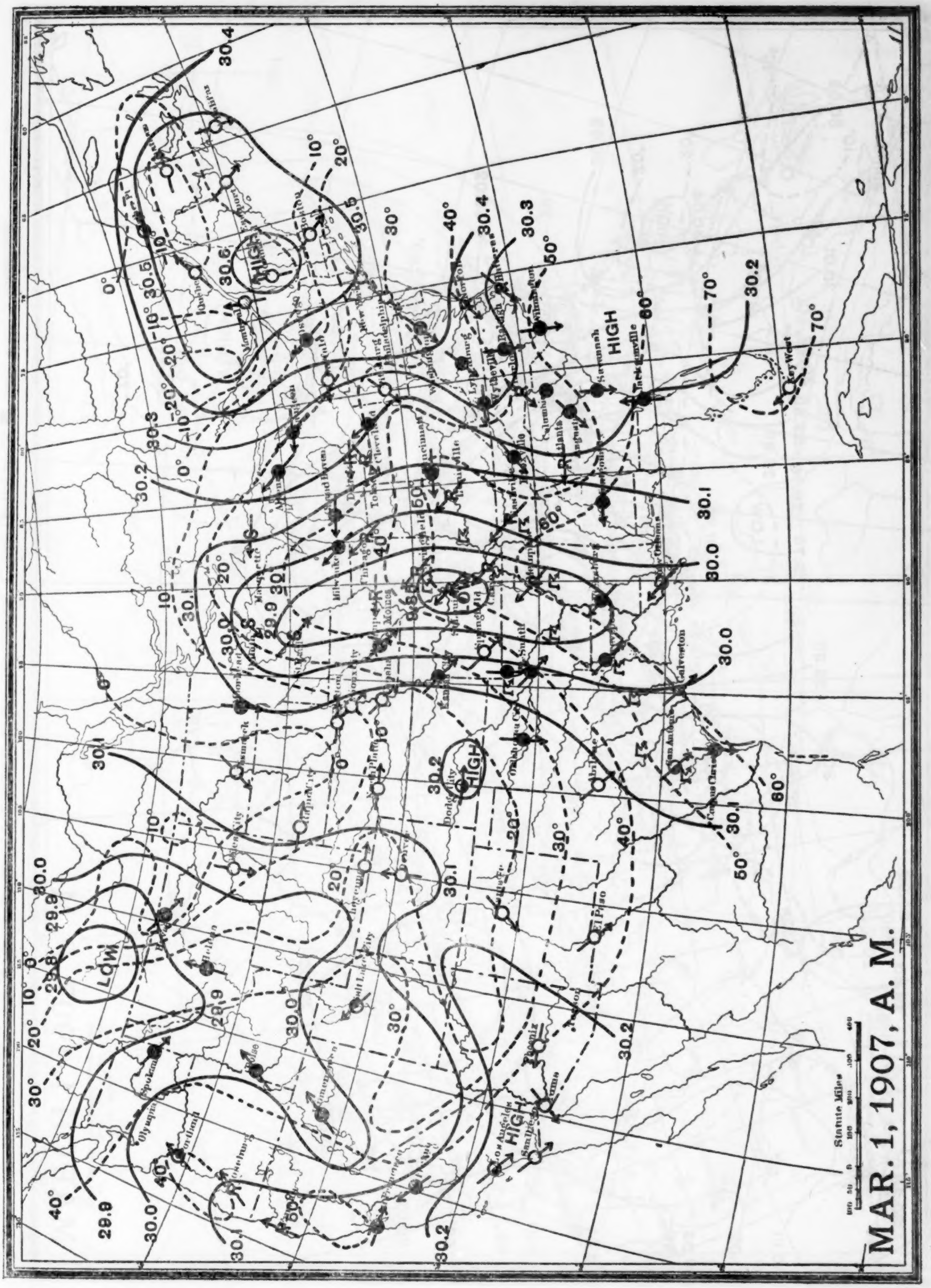

FIG. 11.—Weather Map, 8 a. m., March 1, 1907, typical of conditions at beginning of "tornadic" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; R thunderstorm.

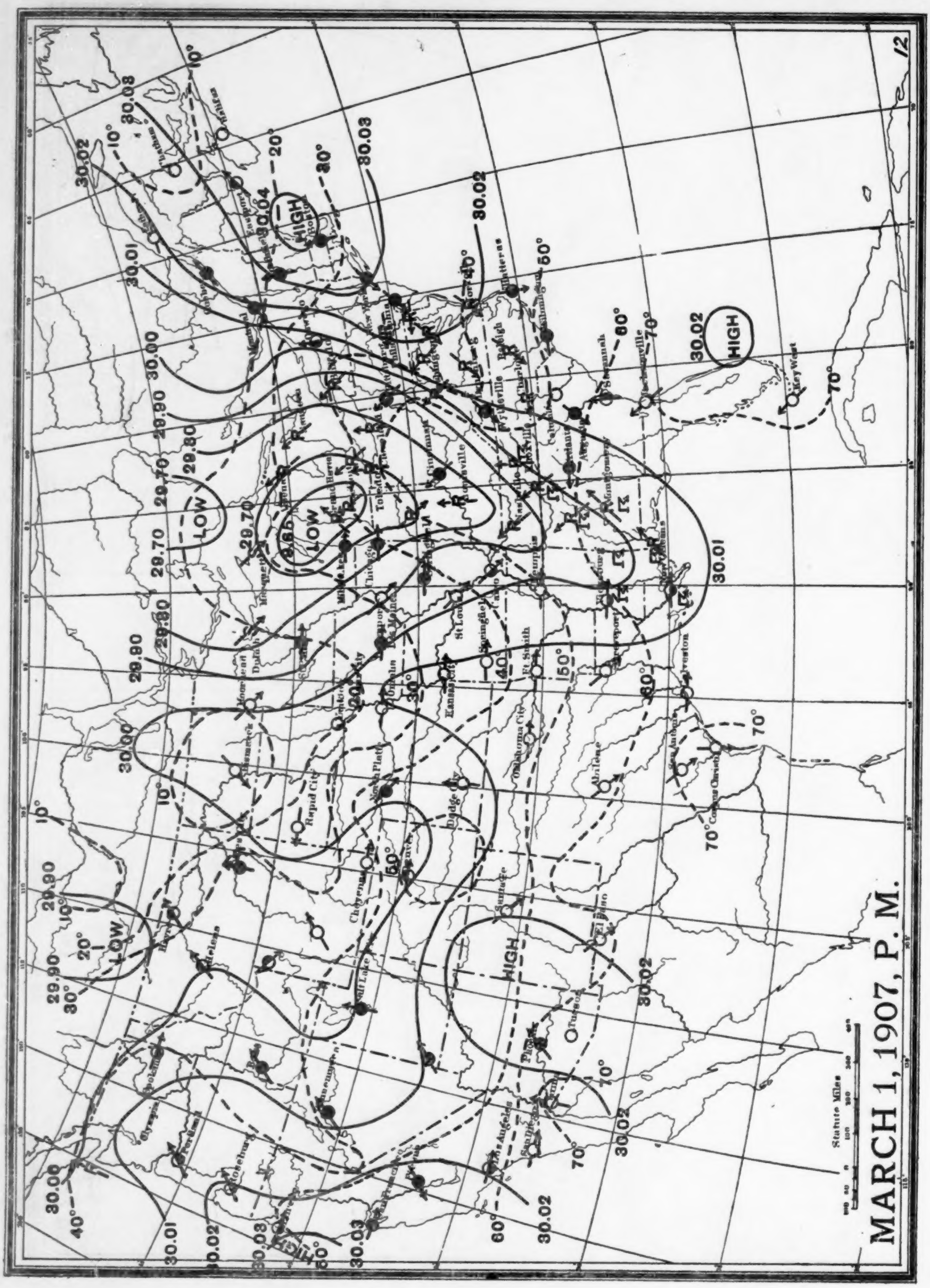

FIG. 12.—Weather Map 8 p. m., March 1 1907, typical of "tornadic" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ↯ thunderstorm.

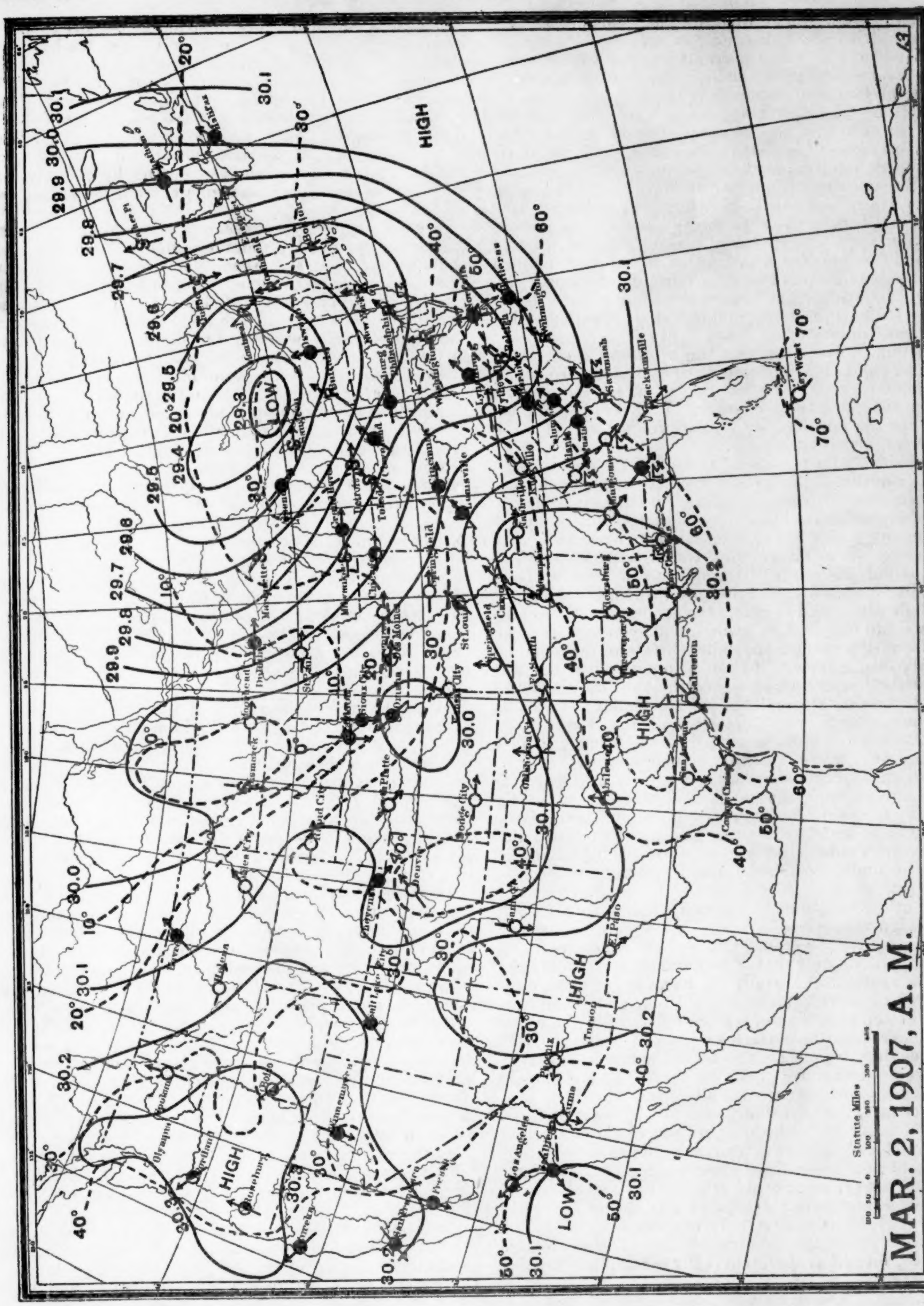

FIG. 13.—Weather Map, 8 a. m., March 2, 1907, typical of conditions at decline of "tornadic" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⚡ thunderstorm.

that hail is often produced. Now this cold rain, or rain and hail, as it falls, and as long as it falls, chills the air from the level of its formation all the way to the earth, partly as a result of its initial low temperature and partly because of the evaporation that takes place during its fall. Hence this continuously chilled column of air because, somewhat, of the frictional drag of the rain, but mainly because of the increase, due to this chilling, of its own density, immediately and necessarily becomes a concentrated and vigorous, or swiftly flowing, return branch of the vertical circulation. In fact, it (or gravity acting through it) becomes the sustaining cause of the storm's circulation. At the same time, because of the downward blow and because of surface friction, as will be explained later, the barometric pressure is abruptly increased.

It will be worth while to consider some of these statements a little more closely, and to test them with possible numerical values.

Omitting, as we may, the effects of radiation, there seem to be but three possible ways by which the cooling of a thunderstorm may be obtained: *a.* By the descent of originally potentially cold air. *b.* By chilling the air with the cold rain. *c.* By evaporation. Each of these will be considered separately.

a. Obviously no portion of the upper air could maintain its position if potentially even slightly colder than that near the surface. If at all potentially colder it would fall until it itself became the surface air, as indeed is the case in all vertical circulation. Hence the great decrease in temperature that comes with a thunderstorm is not the result of the descent of a layer of air originally potentially cold for, as explained, an upper layer sufficiently cold to give, after its descent, the actual cooling could not exist. Again, any descending air must come from either below the under surface of the cloud or from above this level. If from below, it must, because of adiabatic heating, reach the earth at substantially the original surface temperature. If from above it would, as is obvious from figure 1, reach the earth even warmer than the original surface temperature. Hence, looked at in any way, case *a* obviously is inadmissible.

b. Let the under surface of the thunderstorm cloud be 1,500 meters above the earth, and the column of air cooled by the cold rain and its evaporation 2,000 meters high. Let the surface temperature be 30° C., and the temperature gradient before the storm begins adiabatic up to the under-cloud level, and let there be a 2-centimeter rainfall.

Now, at the temperature assumed, a column of air 2,000 meters high whose cross section is 1 square centimeter weighs, roughly, 210 grams, and its heat capacity, therefore, is approximately that of 50 grams of water. At the top of this column the temperature can be, at most, only about 20° C. lower than at the bottom, and if the rain leaves the top at this temperature but reaches the earth 7° C. colder than the surface air before the storm (temperatures that seem at least to be of the correct order) it will have been warmed 13° C. during its fall and the air column cooled on the average about 0.5° C. But, as a matter of fact, the air usually is cooled by from 5° C. to 10° C. Hence, while the temperature of the air necessarily is reduced to some extent by mere heat conduction to the cold rain much the greater portion of the cooling clearly must have some other origin. Further, since *a* is inadmissible and *b* only a minor contributing factor, it follows that by exclusion only evaporation, is left to account for much the greater portion of the cooling. Let us see, then, if evaporation really is adequate to meet these demands.

c. It is a common thing in semiarid regions to see a heavy shower, even a thundershower, leave the base of a cloud and yet fail utterly, because of evaporation, to reach the surface of the earth. Hence it appears quite certain that in the average thunderstorm a considerable portion of the rain that leaves the cloud is evaporated before it reaches the ground, and therefore that the temperature decrease of the atmosphere is largely owing to this fact. But if so, why, then, one might properly ask, does not an equally great temperature drop accompany all heavy rains?

The answer is obvious, because, as a rule, the temperature is higher and the relative humidity lower during a thunderstorm than at the time of any other ordinary rain. The chief, perhaps the sole, reason for this difference in relative humidity is the difference in the two cases, between the movements of the air. In the thunderstorm the descending air, which can be no more than saturated at top, dynamically warms so rapidly and is so continuously renewed that evaporation into it can not keep pace with its vapor capacity. During other rains, however, where there is no atmospheric descent, and therefore no dynamical heating, approximate saturation must soon obtion; hence but little further evaporation and, of course, but little cooling.

We will now return to the numerical values and compute a probable magnitude of cooling due to evaporation.

As before, let a 2-centimeter rain leave the cloud, but let one-fourth of the rain that started, or half a centimeter, be evaporated. This would consume 303 heat units from an air column 2,000 meters high whose heat capacity is that of only 50 cubic centimeters of water. Hence, as a result of evaporation alone, the temperature of the air column would be lowered on the average by about 6° C. Evaporation, therefore, appears to be both necessary and sufficient to produce all or nearly all the cooling of a thunderstorm.

Since the molecular weight of water is 18 while the average molecular weight of air is approximately 29, it follows that the amount of evaporation above assumed would decrease the density of the atmosphere by, roughly, one part in a thousand. On the other hand, a decrease in temperature of 6° C., that would be produced by the evaporation assumed, would increase the density by about one part in fifty. Hence the resultant of these two opposing effects is substantially that of the second alone; that is, a distinct increase in the density.

Doubtless, as already stated, the evaporation of thunderstorm rain, and therefore the drop in temperature and the consequent gain in density, all increase with decrease of elevation. In some measure, however, this effect is counteracted by the increasing rate of dynamical heating in the lower layers resulting from the correspondingly increased rate of pressure gain to change in elevation.

But no matter how nor to what extent the details may vary, it seems quite certain that the cold rain of a thunderstorm and its evaporation together must establish a local downrush of cold air—an observed important and characteristic phenomenon, really the immediate cause of the vigorous circulation, whose rational explanation has been attempted in the past few paragraphs.

As the column or sheet of cold air flows down it maintains in great measure its original velocity and, therefore, on reaching the earth rushes forward in the direction of the storm movement, underrunning and buoying up the adjacent warm air. And this condition, largely due, as explained, to condensation and evaporation, once established necessarily is self-perpetuating, so long as the general temperature gradient, humidity, and wind

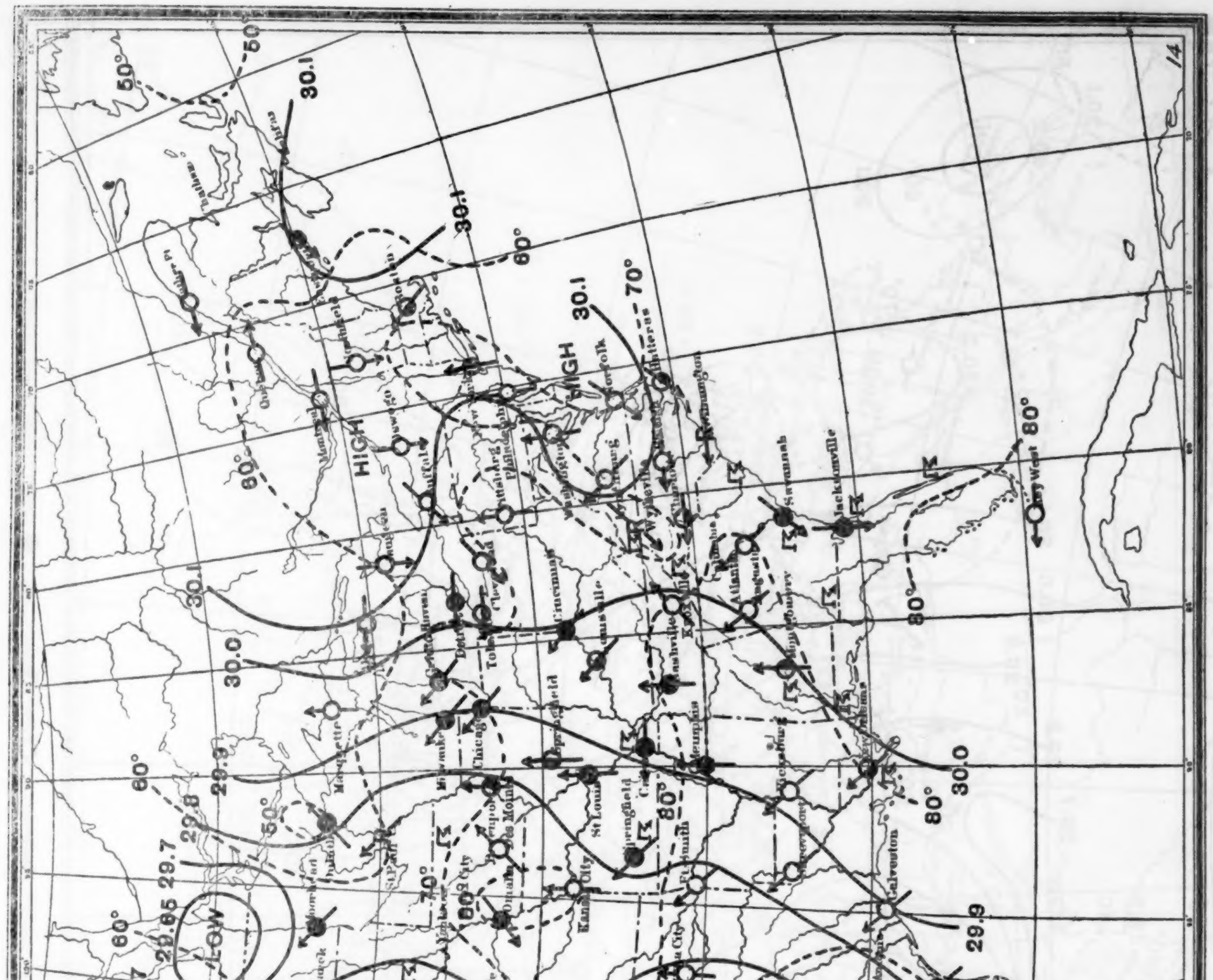

FIG. 14.—Weather Map, 8 p. m., June 12, 1908, typical of conditions at beginning of "trough" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⨅ thunderstorm.

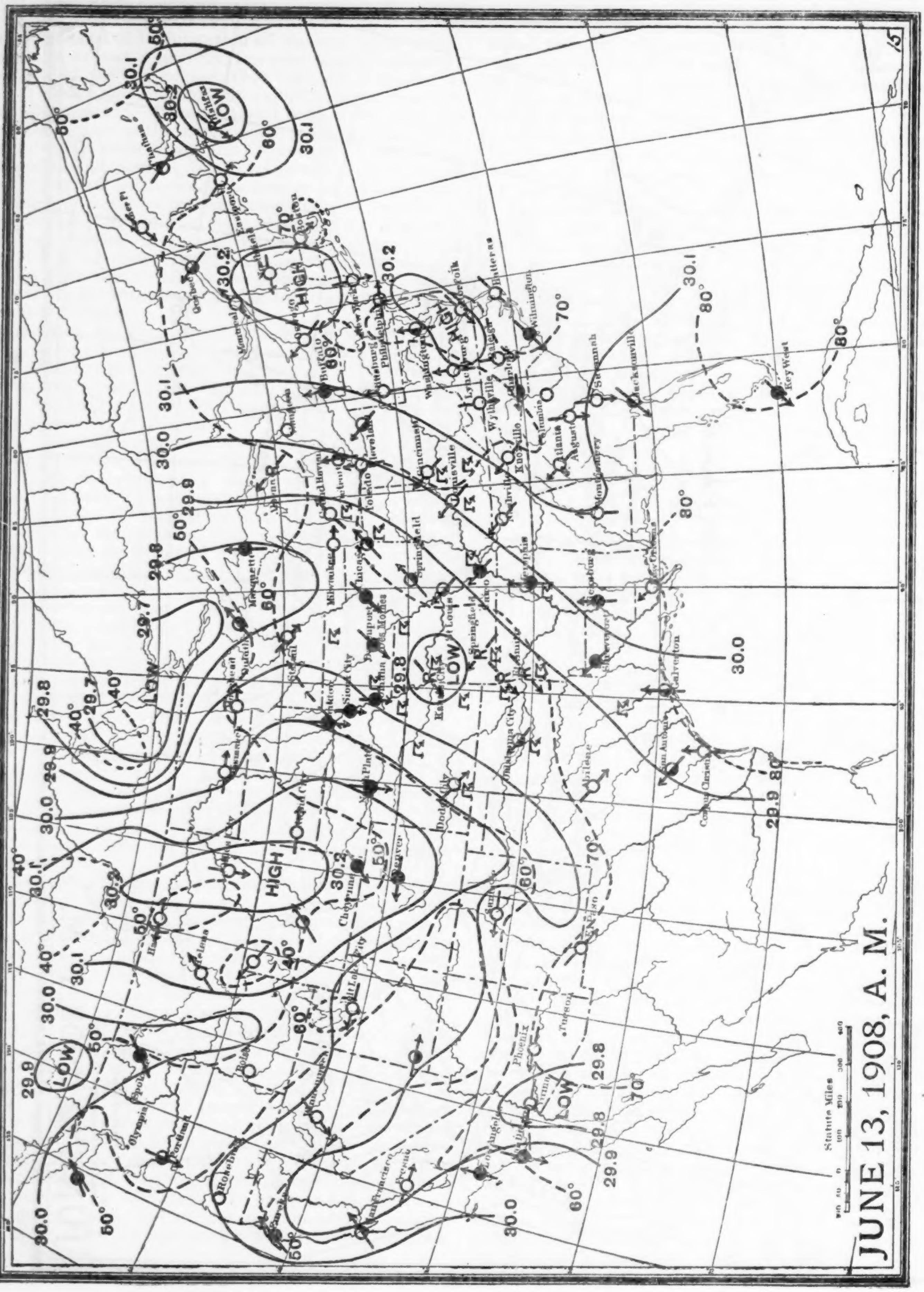

FIG. 15.—Weather Map, 8 a. m., June 13, 1908, typical of "trough" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ↯ thunderstorm.

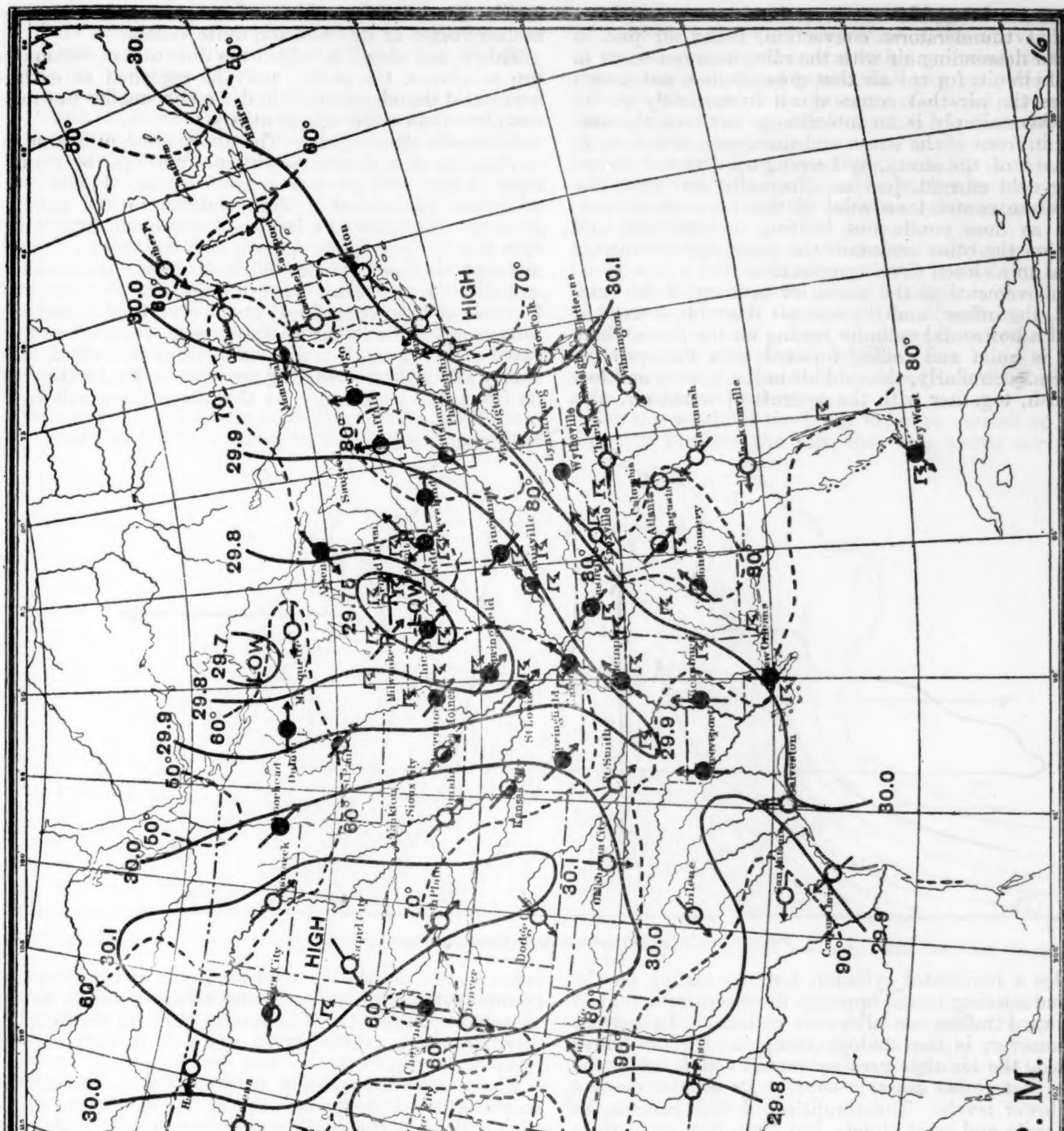

FIG. 16.—Weather Map, 8 p. m., June 13, 1908, typical of conditions at decline of "trough" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R Rain; ☈ thunderstorm.

direction are favorable. It must be remembered, however, that thunderstorm convection, rising air just in front and descending air with the rain, does not occur in a closed circuit, for the air that goes up does not return nor does the air that comes down immediately go up again, there simply is an interchange between the surface air in front of the storm and the upper air in its rear. The travel of the storm, by keeping up with the underrunning cold current, just as effectually maintains the temperature contrast essential to this open-circuit convection as does continuous heating on one side and cooling on the other maintain the temperature contrast essential to a closed circuit convection.

The movements of the warm air in front of the rain, the lull, the inflow, and the updraft resemble somewhat those of a horizontal cylinder resting on the earth where the air is quiet and rolling forward with the speed of the storm. Similarly, the cold air in its descent and forward rush, together with the updraft of warm air, also resembles a horizontal cylinder, but one sliding on the earth and turning in the opposite direction from that of the forward rolling or all-warm cylinder. In neither case, however, is the analogy complete, for, as above explained, the air that goes up remains aloft while the cold air that comes down is kept by its greater density to the lower levels. The condition of flow persists, as do cataracts and crest clouds, but here, too, as in their case, the material involved is ever renewed.

The squall cloud.—Between the uprising sheet of warm air and the adjacent descending sheet of cold air horizontal vortices are sure to be formed in which the two currents are more or less mixed. The lower of these vortices can only be *inferred* as a necessary consequence of the opposite directions of flow of the adjacent sheets of warm and cold air, for there is nothing to render them visible. Neither can any vortices that may exist within the cloud be seen. Near the front lower edge of the cumulo-nimbus system, however, and immediately in front of the sheet of rain, or rain and hail, the rising air has so nearly reached its dew point that the somewhat lower temperature, produced by the admixture of the descending cold air, is sufficient to produce in it a light foglike condensation which, of course, renders any detached vortex at this position quite visible.

This squall cloud, in which the direction of motion on top is against the storm, may be regarded as a third horizontal thunderstorm cylinder much smaller but more complete than either of the others.

Schematic illustrations.—The above conceptions of the mechanism of a thunderstorm can, perhaps, be made a little clearer with the aid of illustrations. Figure 21, a schematic picture of a thunderstorm in the making, gives the boundary of a large cumulus cloud from which rain has not yet begun to fall, and the stream lines of atmospheric flow into it. When the cloud is stationary and there is no surface wind the updraft obviously will be more or less symmetrical about a vertical through its center, but when it has an appreciable velocity, as indicated in the figure, it is equally obvious that most, often nearly all, of the air entering the cloud will do so through its front under-surface. At this stage there will be no concentrated or local down current, only an imperceptible counter settling of the air round about, because, as previously explained, the air cataract requires local cooling to subpotential temperatures, and this in turn requires local rain.

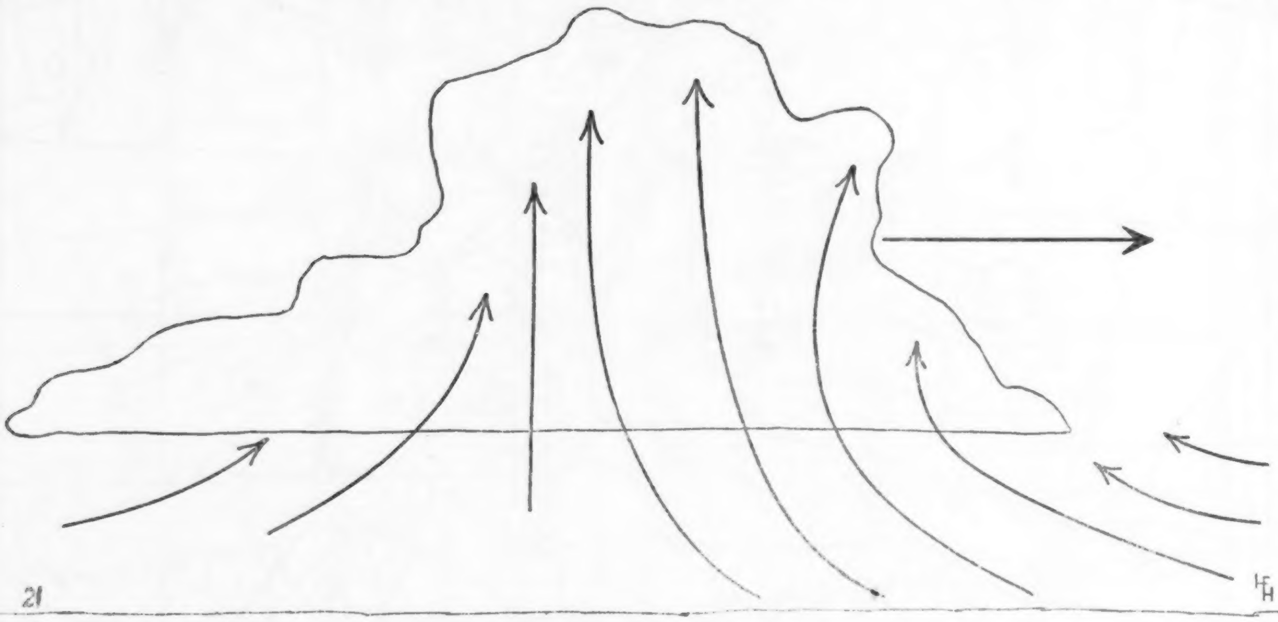

FIG. 21.—Principal air movements in the development of a cumulus cloud.

Figure 22 schematically represents a well-developed thunderstorm in progress. The falling rain, often mixed with hail, cools the air through which it falls, and as the temperature gradient was already closely adiabatic it follows that the actual temperatures will be subpotential from the surface of the earth to within the cloud, or throughout and a little beyond the nonsaturated or evaporating levels. As soon, then, as this column or sheet of air is sufficiently cooled it flows down and forward and all the atmospheric movements peculiar to the thunderstorm are established substantially as shown.

Referring to the figure: The warm ascending air is in the region A; the cold descending air at D; the dust cloud (in dry weather) at D′, the squall cloud at S; the storm collar at C; the thunder heads at T; the hail at H; the primary rain, due to initial convection, at R; and the secondary rain at R′. This latter phenomenon, the secondary rain, is a thing of frequent occurrence and

often is due, as indicated in the figure, to the coalescence and quiet settling of drops from an abandoned portion of the cumulus in which and below which winds and convection are no longer active.

Mammato-cumuli rarely, false cirri frequently, and cap-clouds occasionally, accompany thunderstorms, but as they are not essential to it they therefore are omitted from the above schematic illustration.

Thunderstorm pressures.—Before the onset of a thunderstorm there usually if not always is a distinct fall in the barometer. At times this fall is extended over several hours, but whether the period be long or short the rate of fall usually is greatest at the near approach of the storm. Just as the storm breaks, however, the pressure rises very rapidly, almost abruptly, usually from 1 to 2 millimeters, fluctuates irregularly, and finally as the storm passes again becomes rather steady but at a somewhat higher pressure than prevailed before the storm began.

The cause of these pressure changes is, doubtless, rather complex. The decrease in the absolute humidity and the decrease in temperature both tend to increase the atmospheric pressure, and, presumably, each contributes its share. Both these effects, however, are comparatively permanent, and while they may be mainly responsible for the increase of pressure that persists after the storm has gone by, they probably are not the chief factors in the production of the initial and quickly produced pressure maximum. Here at least two factors, one obvious, the other inconspicuous, are involved. These are: *a.* The rapid downrush of air, and *b.* the interference to horizontal flow caused by the vertical circulation.

The downrush of air clearly produces a vertically directed pressure on the surface of the earth, in the same manner that a horizontal flow produces a horizontally directed pressure against the side of a house. But a pressure equal to that given by 2 mm. of mercury, a pressure increase frequently reached in a thunderstorm, would mean about 2.72 grams per square centimeter, or 27.2 kilograms per square meter, and require a wind velocity of roughly 50 kilometers per hour or 14 meters per second. Now, the velocity of the downrush of air in a thunderstorm is not at all accurately known, but while at times probably very considerable, the above value of 14 meters per second seems to be excessive; in fact, its average value may not be even half so great. If in reality it is not, then, since the pressure of a wind varies as the square of its velocity, it follows that less than one-fourth of the actual pressure increase can be caused in this way. Hence it would seem that there probably is at least one other pressure factor, and, indeed, such a factor obviously exists in the check to the horizontal flow caused by vertical convection.

To make this point clear: Assume two layers of air, an upper and a lower, flowing parallel to each other. Let their respective masses per unit length in the direction of their horizontal movement be M and m, and their velocities V and v. Now, if, through convection, say, the whole or any portion of the lower layer is carried aloft, obviously it must be replaced below by an equal amount of the upper layer.

Let the whole of the lower layer be carried up. This layer, to produce the rain that was above assumed, 2 centimeters, will have to be at least 1 kilometer deep, and if it should merely change places with the upper air, or if the different layers should mingle and assume a common velocity, V', there obviously would be no change in the total linear momentum, nor in the flow. In symbols we would have the equation

$$MV + mv = (M+m)\ V'.$$

Mere mingling, therefore, of the two air currents, upper and lower, can not change the depth of the atmosphere, nor, therefore, the height of the barometer. But then in the case of atmospheric convection we have something more than the simple mingling of two air currents, and the linear momentum does not, in general, remain constant. The increased surface velocity following convection, a phenomenon very marked in the case of a thunderstorm, causes an increased frictional drag and therefore a greater or less decrease in the total flow. Suppose this amounts to the equivalent of reducing the velocity of a layer of air only 25 meters thick from V to v, and let $V = 5v$. That is, the one three hundred and twentieth part of the atmosphere has its flow reduced to

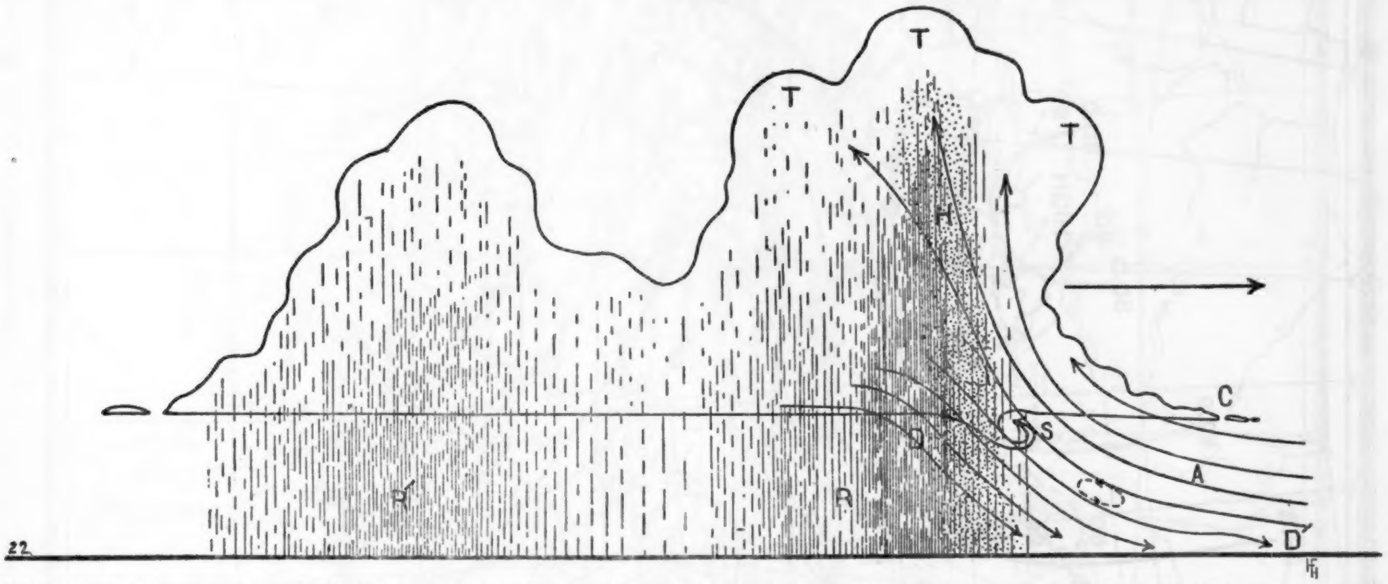

FIG. 22.—Ideal cross section of a typical thunderstorm. A ascending air, D descending air, C storm collar (Sturmkragen), S roll scud, D' wind gust, H hail, T thunderheads, R primary rain, R' secondary rain.

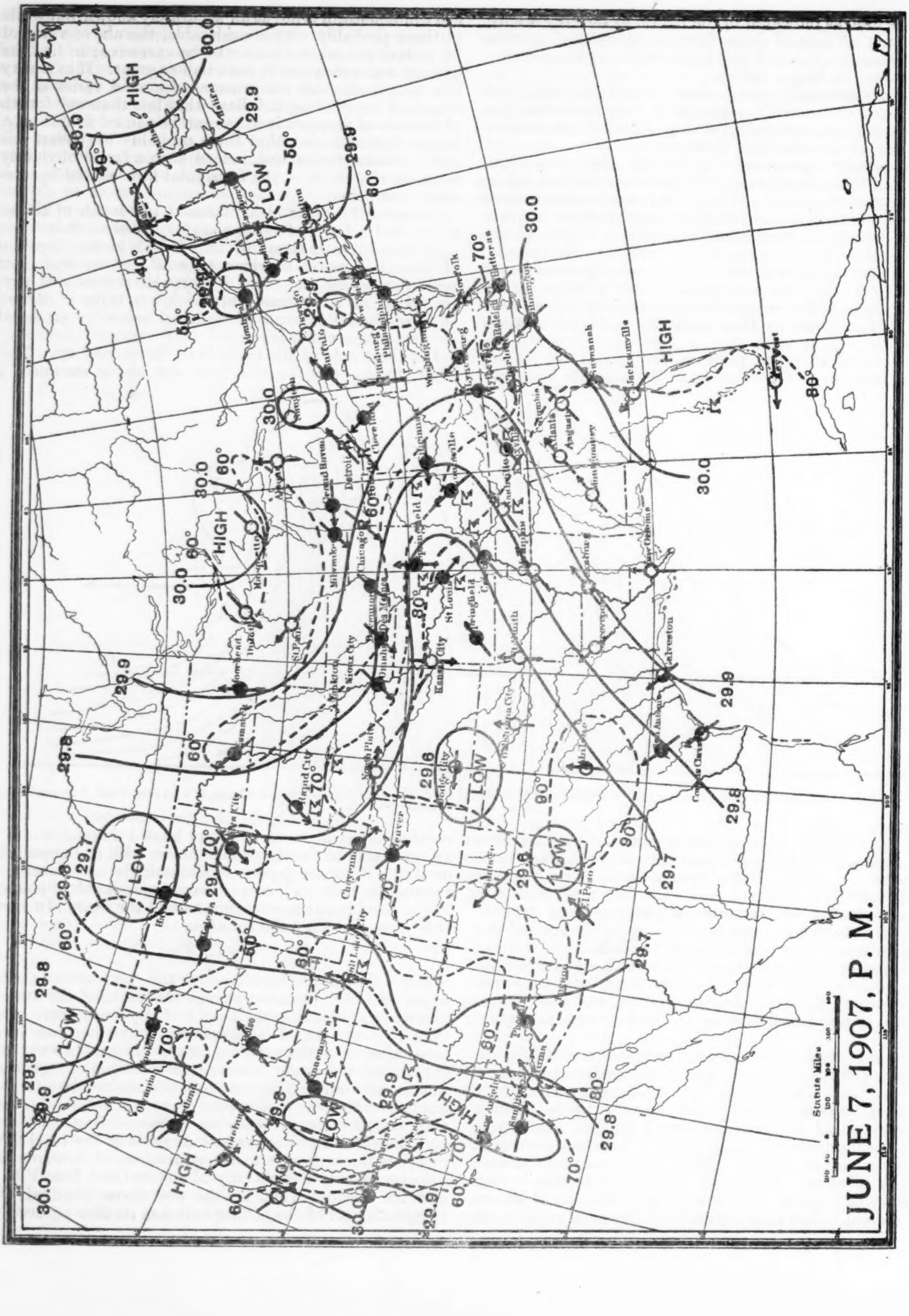

FIG. 17.—Weather Map, 8 p. m., June 7, 1907, typical of conditions at beginning of "border" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⊼ thunderstorm.

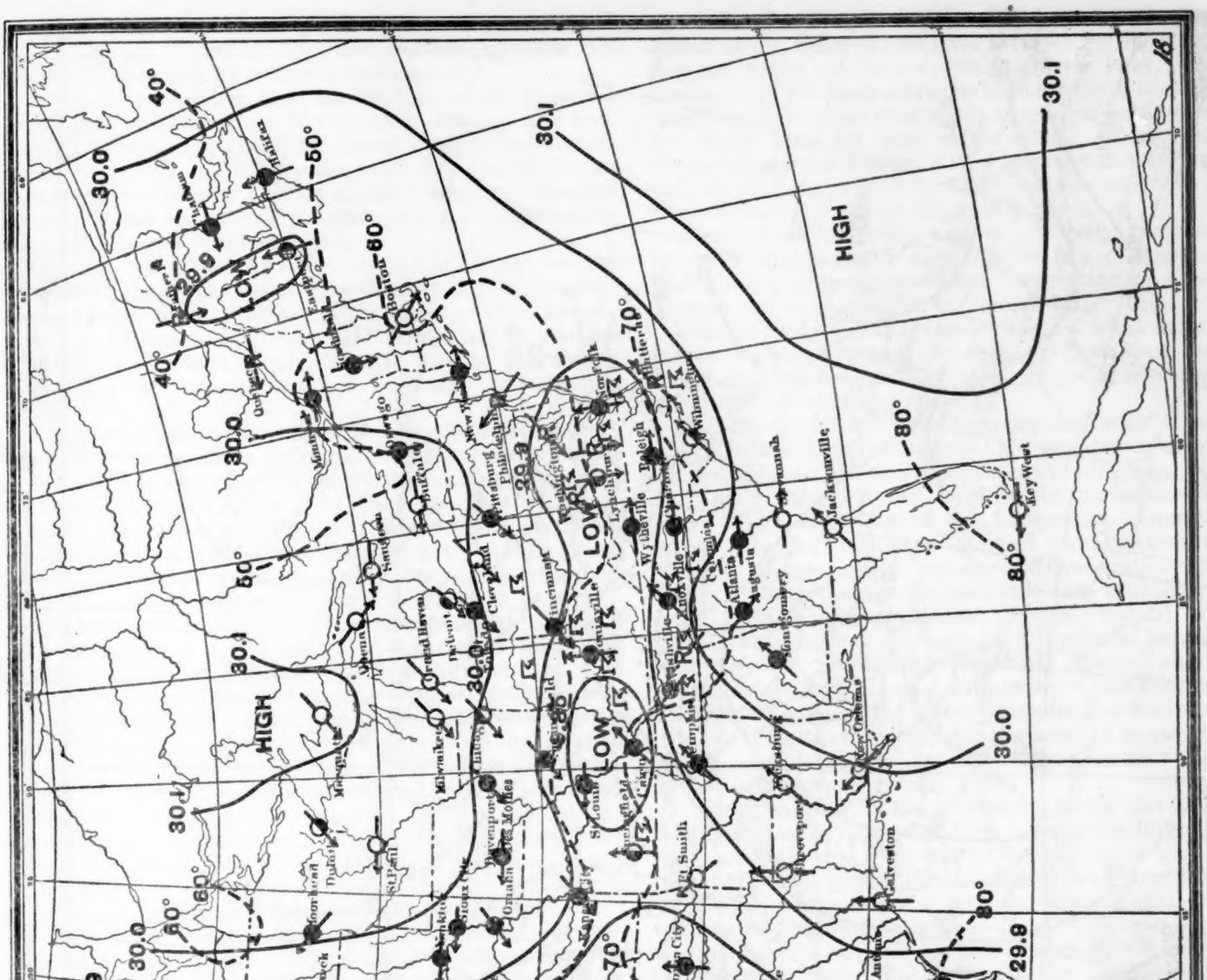

FIG. 18.—Weather Map, 8 a. m., June 8, 1907, typical of "border" thunderstorms. ○ clear; ◐ partly cloudy; ● cloudy; R rain; ⩘ thunderstorm.

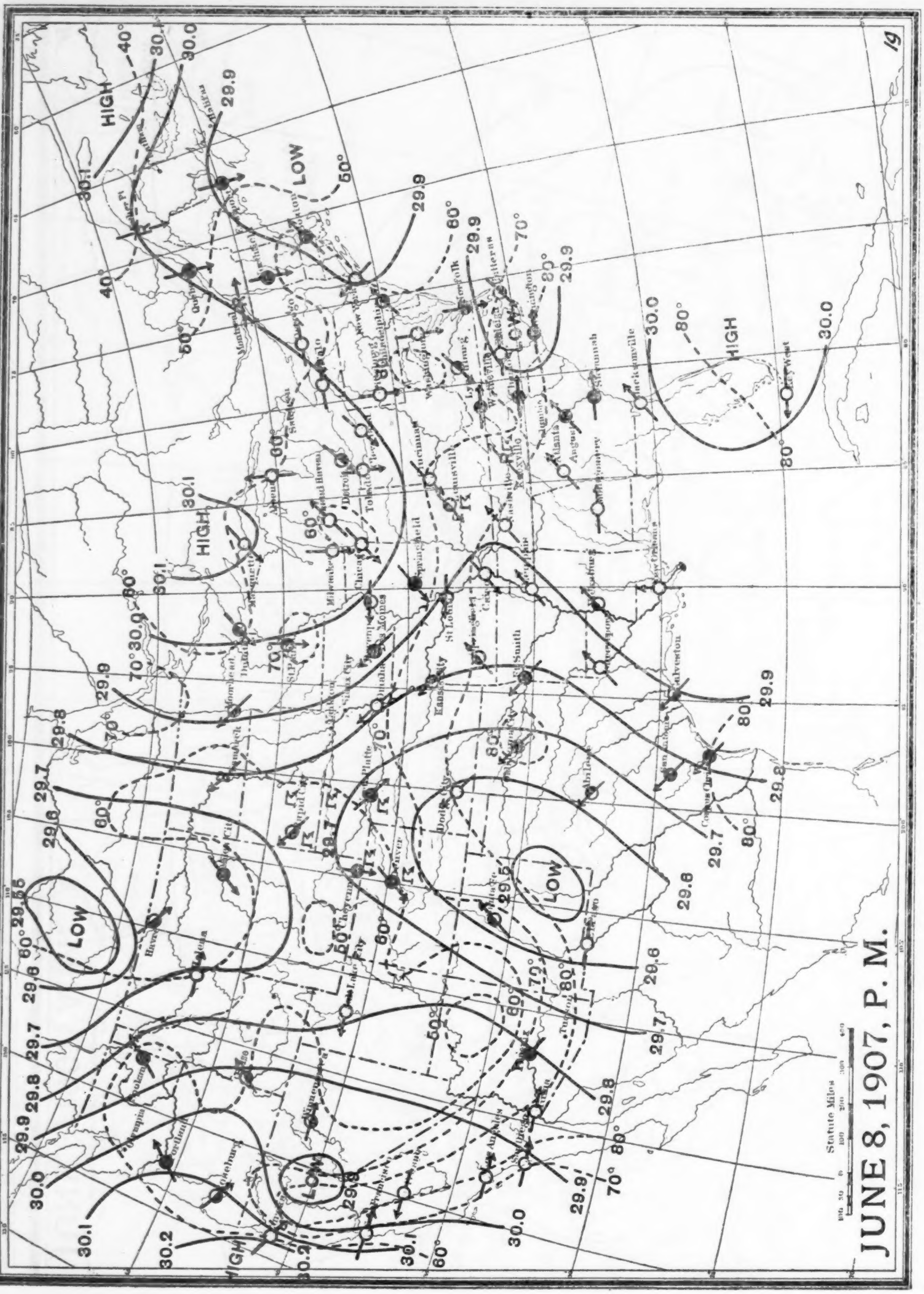

FIG. 19.—Weather Map, 8 p. m., June 8, 1907, typical of conditions at decline of "border" thunderstorms. ○ clear; ◑ partly cloudy; ● cloudy; R rain; Ṟ thunderstorm.

one-fifth its former value. This would reduce the total flow by about 1 part in 400, and thereby increase the barometric reading by nearly 2 millimeters.

It would seem, then, that the friction of the thunderstorm gust on the surface of the earth, through the consequent decrease in the total linear momentum of the atmosphere and, therefore, its total flow, must be an important contributing cause of the rapid and marked increase of the barometric pressure that accompanies the onset of a heavy thunderstorm.

To sum up: The chief factors contributing to the increase of the barometric pressure during a thunderstorm appear to be, possibly in the order of their magnitude: *a*. Decrease of horizontal flow, due to surface friction. *b*. Vertical wind pressure, due to descending air. *c*. Lower temperature. *d*. Decrease in absolute humidity.

Thunderstorm temperatures.—Before the onset of the storm the temperature commonly is high, but it begins rapidly to fall with the first outward gust and soon drops often as much as 5° C. to 10° C. because, as already explained, this gust is a portion of the descending air cooled by the cold rain and by its evaporation. As the storm passes the temperature generally recovers somewhat, though it seldom regains its original value.

Thunderstorm humidity.—As previously explained, heavy rain, at least up in the clouds, and therefore much humidity, and a temperature contrast sufficient to produce rapid vertical convection, are essential to the genesis of a thunderstorm. Hence during the early forenoon of a thunderstorm day both the absolute and the relative humidity are likely to be high. Just before the storm, however, when the temperature has greatly increased, though the absolute humidity still is high, the relative humidity is likely to be rather low. On the other hand, during and immediately after the storm, because chiefly of the decrease in temperature, the absolute humidity is comparatively low and the relative humidity high.

"Rain-gush."—It has frequently been noted that the rainfall is greatest after heavy claps of thunder, a fact that appears to have given much comfort and great encouragement to those who maintain the efficacy of mere noise to induce precipitation—to jostle cloud particles together into raindrops. The correct explanation, however, of this phenomenon seems obvious: The violent turmoil and spasmodic movements within a large cumulus or thunderstorm cloud cause similar irregularities in the condensation and resulting number of raindrops at any given level. These in turn, as broken by the air currents, give local excess of electrification and of electric discharge or lightning flash. We have, then, starting toward the earth at the same time and from practically the same level, mass, sound, and light. The light travels with the greatest velocity, about 300,000 kilometers per second, and therefore the lightning flash is seen before the thunder is heard; its velocity being, roughly, only 330 meters per second. But the rain falls much slower still and therefore reaches the ground after the thunder is heard. In reality it is the excessive condensation or rain formation up in the cumulus cloud that causes the vivid lightning and the heavy thunder. According only to the order in which their several velocities cause them to reach the surface of the earth it might appear, and has often been so interpreted, that the lightning, first perceived, was the cause of the thunder, which, indeed, it is, and that the heavy thunder, next in order, was the cause of the excessive rain, which most certainly it is not.

Thunderstorm velocity.—The velocity of the thunderstorm is simply the velocity of the atmosphere in which the bulk of the cumulus cloud happens to be located. Hence as the wind at this level is faster by night than by day and faster over the ocean than over land, it follows that exactly the same relations hold for the thunderstorm, that it travels faster over water than over land and faster by night than by day. The actual velocity of the thunderstorm, of course, varies greatly, but its average velocity in Europe is 30 to 50 kilometers per hour; in the United States, 50 to 65 kilometers per hour.

Hail.—Hail, consisting of lumps of roughly concentric layers of compact snow and solid ice, is a conspicuous and well-known phenomenon that occurs during the early portion of most severe thunderstorms. But in what portion of the cloud it is formed and by what process the layers of ice and snow are built up are facts that, far from being obvious, become clear only when the mechanism of the storm itself is understood.

As before, let the surface temperature be 30° C. and the absolute humidity 40 per cent, or the dew point 15° C. Under these conditions saturation will obtain, and, therefore, cloud formation will begin when the surface air has risen to an elevation of 1.5 kilometers. Immediately above this level the latent heat of condensation reduces the rate of temperature decrease with elevation to about half its former value, nor does this rate rapidly increase with further gain of height. Hence, usually, for the above assumptions correspond in general to average thunderstorm conditions, it is only beyond the 4-kilometer level that freezing temperatures are reached. It is therefore only in the upper portions of cumulus clouds, the portions that clearly must consist of snow particles and undercooled fog or cloud droplets, that hail can either originate or greatly grow.

But what, then, is the process by which the nucleus of the hailstone is formed and its layer upon layer of snow and ice built up? Obviously such drops of rain as the strong updraft within the cloud may blow into the region of freezing temperatures will quickly congeal and also gather coatings of snow and frost. After a time each incipient hailstone will get into a weaker updraft, for this is always irregular and puffy, or else will tumble to the edge of the ascending column. In either case it will then fall back into the region of liquid drops, where it will gather a coating of water, a portion of which will at once be frozen by the low temperature of the kernel. But again it meets an upward gust, or falls back where the ascending draft is stronger, and again the cyclic journey from realm of rain to region of snow is begun; and each time—there may be several—the journey is completed a new layer of ice and a fresh layer of snow are added. In general the size of the hailstones will be roughly proportional to the strength of the convection current, but since their weights vary approximately (they are not homogeneous) as the cube of their diameters while the supporting force of the upward air current varies, also approximately, as only the square of their diameters it follows that a limiting size is quickly reached. It is also evident, from the fact that a strong convection current is essential to the formation of hail, that it can occur only where this convection exists; that is, in the front portion of a heavy to violent thunderstorm.

Some meteorologists hold that the roll scud between the ascending warm and descending cold air is the seat of hail formation, but this is a mistaken assumption. Centrifugal force would throw a solid object, like a hailstone, out of this roll probably before a single turn had been completed. Besides, and this objection is, perhaps, more obviously fatal than the one just given, the temperature of the roll scud, because of its position, the

lowest of the whole storm cloud, clearly must be many degrees above the freezing point. Indeed, as the above calculation shows, temperatures low enough for the formation of hail can not often obtain at levels much less than three times that of the scud, and therefore it clearly is in the higher levels of the cumulus and not in the low scud that hail must have its genesis and make its growth.

Lightning.—About the middle of the eighteenth century Franklin and others clearly demonstrated that the lightning of a thunderstorm and the discharge of an ordinary electric machine are identical in nature, and thereby established the fact that many of the properties of the former may logically be inferred from laboratory experiments with the latter. There is, however, one important source of difference between the two phenomena that does not seem always to be clearly kept in mind, namely, the distribution of the charge. In the one case, that of the laboratory experiment, the charge commonly exists almost wholly on the surface of the apparatus used, while in the other, that of the thunderstorm, it is irregularly distributed throughout the great cloud volume. Hence the two discharges, lightning and laboratory sparks, necessarily differ from each other in important details. Nevertheless in each case the atmosphere must be ionized before the discharge can take place freely, and this condition seems, at times at least, to establish itself progresso-spasmodically. That is, a small initial discharge, losing itself in a terminal brush, is rapidly followed by another and another, each losing itself in a manner similar to the first, until a path from pole to pole is sufficiently ionized to permit of a free flow and quick exhaustion of the remaining charge. Figure 23, copied from a photograph obtained by Walter (**9**), on a rapidly moving plate, shows how a laboratory spark spasmodically (doubtless at the period of electrical oscillation) ionizes the air from either pole and thus progressively extends and finally closes the conducting path of complete discharge. There appears also to be good evidence that the lightning discharge often builds itself up in a manner generally similar, though, perhaps, radically different, in certain details. As already implied, ordinary laboratory apparatus has a free period of electrical oscillation, and therefore an electrical discharge from such apparatus is oscillatory in nature, but as yet there seems to be no certain evidence that lightning discharges ever are distinctly oscillatory. They frequently are pulsatory, discharge after discharge taking place in the same direction and along the same path, as we shall see later; but this is an entirely different thing from being oscillatory, or consisting of a decreasing series the units of which are alternately in opposite directions.

It will be convenient, in further discussing the facts known about lightning, to classify it according to its general appearance.

Streak lightning.—When the storm is close by, the lightning discharge almost invariably appears to the unaided eye as one or more sinuous lines or streaks of vivid white or pink. Sinuous, because electrically the atmosphere is heterogeneous or unequally ionized. There often appears to be a main trunk with a number of branches, all occurring at the same time and instantaneously. At other times there seem to be two or more simultaneous but locally disconnected streaks. Frequently the discharge continues flickeringly (on rare occasions even steady, like a white-hot wire) during a perceptible time—occasionally a full second.

But all these phenomena are best studied by means of the camera, and have been so studied by several persons, among whom Walter, of Hamburg, and Larsen, of Chicago, are two of the most persistent and successful. Stationary cameras, revolving cameras, stereoscopic cameras, cameras with revolving plates, and cameras with spectrographic attachments have all been used, separately and jointly, and the results have abundantly justified the time and the labor devoted to the work.

Figure 24, copied by permission from one of Walter's unpublished negatives, shows the ordinary tracery of a lightning discharge when photographed with a stationary camera. It is only a permanent record of the appearance of the lightning to the unaided eye. Figure 25, however, also copied by Walter's kind permission from one of his unpublished photographs, is a record of the same discharge obtained with a rotating camera. It will be noted that the more nearly vertical discharge occurred but once or was single; that this discharge was quickly followed by a second along the same path to about one-fourth of the way to the earth where it branched off on a new course; that the second discharge was followed in turn at short but irregular intervals by a whole series of sequent discharges; that most of the discharges appeared as narrow intensely luminous streaks, and that one of the sequent discharges appeared, not to the eye, but on the plate of the rotating camera, as a broad band or ribbon. On close inspection it will be obvious that the plaidlike ribbon effect is due, the warp to irregularities in the more or less continuous discharge, and the woof to roughly end-on and therefore brighter portions of the streak. Another point particularly worthy of attention is the fact that while the first discharge has several side branches the following ones remain entire from end to end and are nowhere subdivided.

Figure 26, taken from a photograph obtained by Mr. Larsen, of Chicago, and kindly loaned for use here by the Smithsonian Institution, shows another series of sequent discharges similar to those of figure 25, except that in this case there was no ribbon discharge. The time of the whole discharge, as calculated by Mr. Larsen, was 0.315 second. Here, too, side branches occur with the first but only the first discharge. This, however, is not an invariable rule for occasionally, as illustrated by figure 27, copied from a published photograph by Walter, the side branches persist through two or three of the first successive discharges, but not through all. In such case each tributary when repeated follows, as does the main stream, its own original channel.

The phenomenon of sequent discharges, all along the same path, and the disappearance of the side branches with or quickly after the first discharge both seem reasonably clear. The first discharge, however produced, obviously takes place against very great resistance, and therefore under conditions the most favorable for the occurrence of side branches or ramifications. But the discharge itself leaves the air along its path temporarily highly ionized—puts a temporary line conductor with here and there a poorer conducting branch, in the atmosphere. This conductor is not only temporary (half the ions are reunited in about 0.15 second, the air being dusty) but also so extremely fragile as to be liable to rupture by the atmospheric violence it itself creates. Because partly, perhaps, of just such interruptions, and because also of the volume distribution of the electricity which prevents a sudden and complete discharge, the actual discharge is divided into a number of partials that occur sequently. Obviously the breaks in the conducting (ionized) path, if they exist, are only here and there and but little more than sufficient to interrupt the flow. Hence the next discharge, if it occurs quickly, must follow the conducting and, therefore, original discharge path. Besides, in the

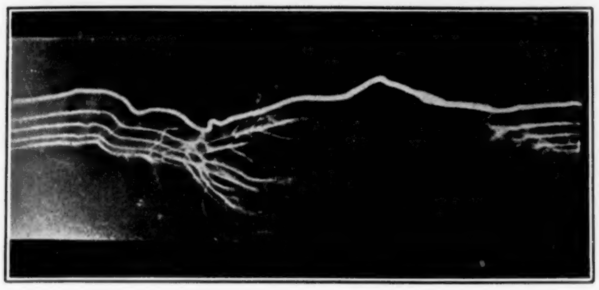

FIG. 23.—The growth of an electric spark discharge (Walter).

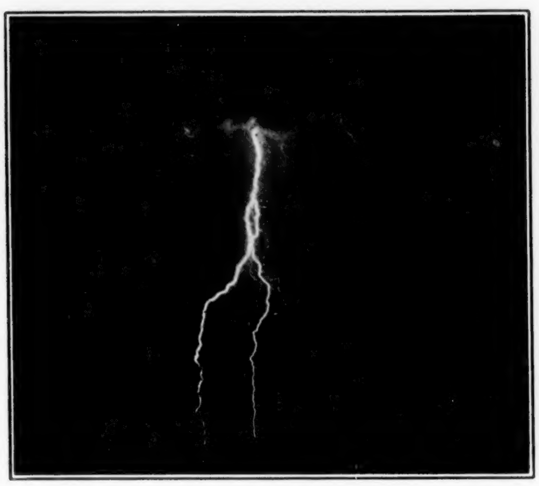

FIG. 24.—Streak lightning, stationary camera; companion to Fig. 25 (Walter).

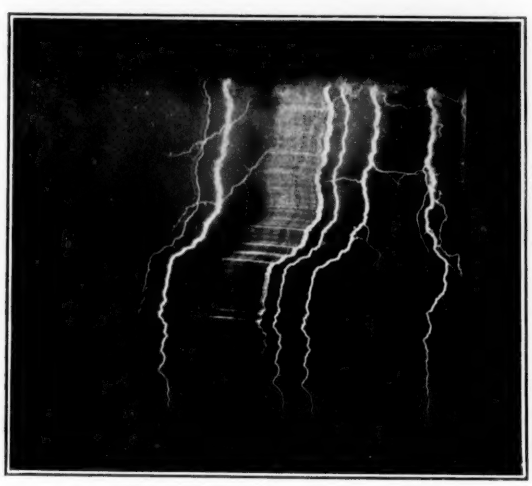

FIG. 25.—Streak lightning (sequent discharges), rotating camera; companion to Fig. 24 (Walter).

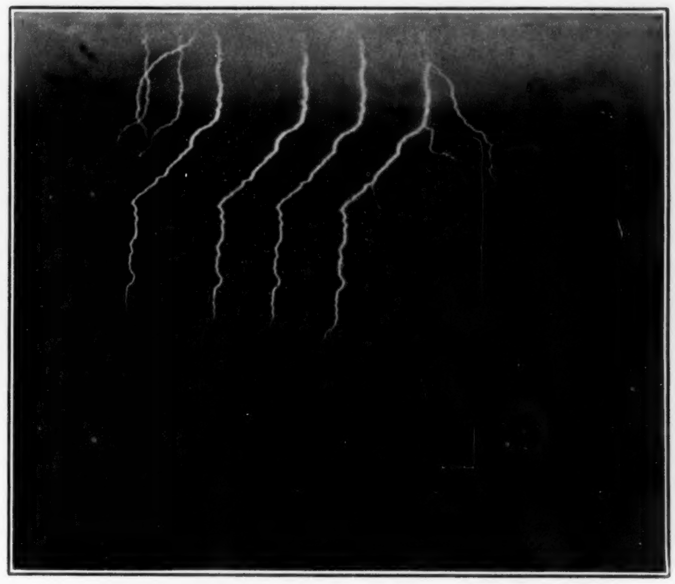

FIG. 26.—Streak lightning (sequent discharges), rotating camera (Larsen).

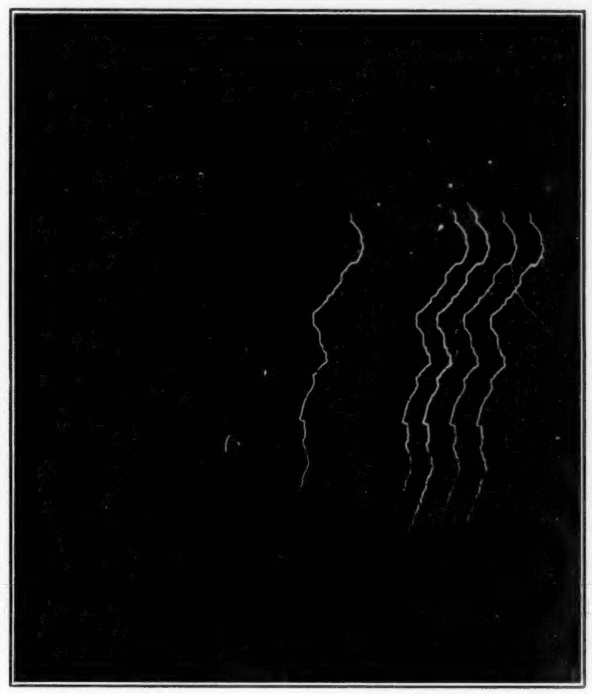

FIG. 27.—Streak lightning (sequent discharges), rotating camera (Walter).

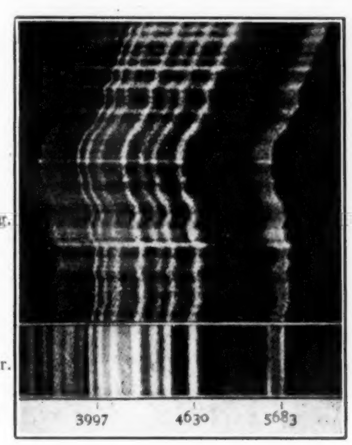

FIG. 28.—Spectrum of lightning (Fox).

subsequent discharges the original side branches will be quickly abandoned because of their greater resistance, or, what comes to the same thing, because of the more abundant ionization and consequent higher conductivity of the path of heaviest discharge.

This leaves the genesis of the initial discharge, often if not usually the only one, to be explained, and indeed this probably is, at present, the least understood of all the many thunderstorm phenomena. Judging from the voltages required to produce laboratory sparks, roughly 30,000 volts per centimeter, it is not obvious how such tremendous voltage differences can be established between clouds or between a cloud and the earth as would seem to be necessary to produce a discharge kilometers in length, as often occurs. Of course the potential of individual drops may grow in either of two ways: *a*. By coalescence of equally charged smaller drops into larger ones. In this case, since capacity is directly proportioned to the radius, the potentials of the individual drops must be proportional to the squares of their radii. *b*. By evaporation of equally charged drops. Here the potentials of the individual drops obviously is inversely proportional to their radii. In each case the tendency of the separate drops to discharge is increased, but the potential of the cloud as a whole remains unchanged. At present, therefore, one can do but little more than speculate on the subject of the primary lightning discharge, but even that much may be worth while since it helps one to remember the facts.

As already explained the electrical separation within a thunderstorm cloud is such as to place a heavily charged positive layer (lower portion of the cloud) between the earth and a much higher, also heavily charged, negative layer (upper portion of the cloud). Hence the discharges, or lightning, from the intermediate or positively charged layer may be either to the negative portion above, in some cases even to an entirely different cloud, or to the earth below. Further, through the sustaining influence and turbulence of the uprushing air there must be formed at times and places practically continuous sheets and streams of water, of course heavily charged and at high potential, and also layers and streaks of highly ionized air; that is, electrically speaking, heavily charged conducting sheets and rods, whether of coalesced drops or of ionized air, are over and over, so long as the storm lasts, momentarily placed here and there within the positively charged mass of the storm cloud.

Let us see, then, what might be expected as the result of this peculiar disposition of charges and conductors, the result, namely, of the existence of a heavily surface-charged vertical conductor in a strongly volume-charged horizontal layer or region above and below which there are steep potential gradients to negatively charged parallel surfaces.

The conductor will be at the same potential throughout, and therefore the maxima of potential gradients normal to it will be at its ends, where, if these gradients are steep enough, and the longer the conductor the steeper the gradients, brush discharges will take place. Assume, then, that a brush discharge does take place and that there is a supply of electricity flowing into the conductor to make good the loss. The brush and the line of its most vigorous ionization necessarily will be directed along the potential gradient or toward the surface of opposite charge. But this very ionization automatically increases the length of the conductor, for a path of highly ionized air is a conductor, and as the length of the conductor grows so, too, does the steepness of the potential gradient at its forward or terminal end, and as the steepness of this gradient increases the more vigorous the discharge, always assuming an abundant electrical supply. Hence, an electric spark once started within a thunderstorm cloud has a good chance, by making its own conductor as it goes, of geometrically growing into a lightning flash of large dimensions. Of course when the electrical supply is small the lightning is feeble and soon dissipated.

Whether the discharge actually does burrow its way through the atmosphere in some such manner as that indicated probably would be difficult, though not necessarily impossible, of observation. Indeed, a roughly analogous phenomenon (**10**) can be produced on a photographic plate by bringing in contact with the film, some distance apart, two conducting points attached to the opposite poles of an influence machine. Brush discharges develop about each point, but the glow at the negative pole detaches itself and slowly meanders across the plate toward the positive point. As it goes it continually builds for itself, out of the silver of the emulsion, a conducting path.

Rocket lightning.—Many persons have observed what at least seemed to be a progressive growth in the length of a streak of lightning. In some cases (**11**) this growth or progression has appeared so slow as actually to suggest the flight of a rocket, hence the name.

At first one might well feel disposed to regard the phenomenon in question as illusory, but it has been too definitely described and too frequently observed to justify such summary dismissal. Naturally, in the course of thousands of lightning discharges, many degrees of ionization, availability of electrical charge, and slopes of potential gradient are encountered. Ordinarily the growth of the discharge, doubtless, is in a geometric ratio and the progress of its end exceedingly swift, but it seems possible for the conditions to be such that the discharge can barely more than sustain itself, in which case the movement of the flash terminal may, possibly, be relatively slow.

Ball lightning.—Curious luminous balls or masses, of which C. De Jans (**12**) probably has given the fullest account, have time and again been reported among the phenomena observed during a thunderstorm. Most of them appear to last only a second or two and to have been seen at close range, some even passing through a house, but they have also appeared to fall, as would a stone (**13**), or like a meteor, from the storm cloud, and along the approximate path of both previous and subsequent lightning flashes. Others appear to start from a cloud and then quickly return, and so on through an endless variety of places and conditions.

Doubtless many reported cases of ball lightning are entirely spurious, being either fixed or wandering brush discharges or else nothing other than optical illusions, due in most cases probably to persistence of vision. But here, too, as in the case of rocket lightning, the amount and excellence of observational evidence forbid the assumption that all such phenomena are merely subjective. Possibly in some instances, especially those in which it is seen to fall from the clouds, ball lightning may be only extreme cases of rocket lightning, cases in which the discharge for a time just sustains itself. A closely similar idea has been developed in detail by Toepler (**14**). It may either disappear wholly and noiselessly, as often reported, or it could perhaps suddenly gain in strength and instantly disappear, as sometimes observed, with a sharp abrupt clap of thunder.

To say that all genuine cases of ball lightning, those that are not mere optical illusions are stalled thunderbolts, certainly may sound very strange. But that

indeed is just what they are according to the above speculation, a speculation that recognizes no difference in kind between streak, rocket, and ball lightning, only differences in the amounts of ionization, quantities of available electricity and steepness of potential gradients.

Sheet lightning.—When a distant thundercloud is observed at night one is quite certain to see in it beautiful illuminations, looking like great sheets of flame, that often flicker and glow in exactly the same manner as does streak lightning for well-nigh a whole second. In the daytime and in full sunlight the phenomenon when seen at all appears like a sudden sheen that travels and spreads here and there over the surface of the cloud. Certainly in most cases, so far as definitely known in all cases this is only reflection from the body of the cloud of streak lightning in other and invisible portions. Conceivably a brush or coronal discharge may take place from the upper surface of a thunderstorm cloud, but one would expect this to be either a faint continuous glow or else a momentary flash coincident with a discharge from the lower portion of the cloud to earth or to some other cloud. But, as already stated, only reflection is definitely known to be the cause of sheet lightning. Coronal effects seem occasionally possible, but that they are ever the cause of the phenomenon in question has never clearly been established and appears very doubtful. It has often been asserted, too, that there is a radical difference between the spectra of streak and sheet lightning, but even this does not appear ever to have been photographically proved.

Beaded lightning.—Discontinuous or beaded streaks of lightning have been reported from time to time. Indeed the author himself has several times seen, or had the impression of seeing, this phenomenon, but with one or two doubtful exceptions he felt practically certain that it was only an optical illusion. In addition to visual observations of the kind just described many photographs showing streaks of light broken into more or less evenly spaced dashes have been obtained and reported as photographs of beaded lightning. Without exception, however, these seem certainly to be nothing other than the photographs of alternating current electric lights, taken with the camera in motion. The objective reality, therefore, of beaded lightning does not seem at all well established, at least not sufficiently well to justify any serious effort to explain it.

Return lightning.—This is commonly referred to as the return shock, and is only those relatively small electrical discharges that take place here and there from objects on the surface of the earth coincidently with lightning flashes, and as a result of the suddenly changed electrical strain. These discharges are always small in comparison with the main lightning flash, but at times they are sufficient to induce explosions, to start fires, and even to take life.

Dark lightning.—When a photographic plate is exposed to a succession of lightning flashes, it occasionally happens that one or more of the streak images, on development, exhibits the "Clayden effect"—that is, appears completely reversed—while the others show no such tendency. Obviously, then, on prints from such a negative the reversed streaks must appear as dark lines, and for that reason the lightning flashes that produced them have been called "dark lightning." There is, of course, no such thing as dark lightning, but the photographic phenomenon that gave rise to the name is real, interesting, and reproducible at will in the laboratory (15).

Temperature.—What the temperature along the path of a lightning discharge is no one knows, but it obviously is high, since it frequently sets fire to buildings, trees, and many other objects struck. In an ordinary electrical conductor the amount of heat generated in a given time by an electric current is proportional to the product C^2RT, in which C is the strength of the current, R the ohmic resistance, and T the time in question during which C and R are supposed to remain constant. In a spark discharge of the nature of lightning some of the energy produces effects, such as decomposition and ionization, other than mere local heating, but as experiment shows, a great deal of heat is generated, according, so far as we know, to the same laws that obtain for ordinary conductors. Hence extra heavy discharges, like extra large currents, produce excessive heating, and therefore are far more liable than are light ones to set on fire any objects that they may hit.

Visibility.—Just how a lightning discharge renders the atmosphere through which it passes luminous is not definitely known. It must and does make the air path very hot, as we have seen, but no one has yet succeeded, by any amount of ordinary heating, in rendering either oxygen or nitrogen luminous. Hence it seems well nigh certain that the light of lightning flashes owes its origin to something other than high temperature, probably to internal atomic disturbances induced by the swiftly moving electrons of the discharge.

Spectrum.—Lightning flashes are of two colors, white and pink or rose. The rose-colored flashes, when examined in the spectroscope, show several lines due to hydrogen which, of course, is furnished by the decomposition of some of the water along the lightning path. The white flashes, on the other hand, show no hydrogen lines or at most but faint ones. As one might suspect, the spectrum of a lightning flash and that of an ordinary electric spark in air are practically identical. This is well shown by figure 28, copied from an article on the spectrum of lightning by Fox (16), in which the upper or wavy portion is due to the lightning and the lower or straight portion to a laboratory spark in air.

It is often asserted that the spectrum of streak lightning consists wholly of bright lines and that sheet lightning gives only nitrogen bands; and from this it is argued that the latter is not a mere reflection of the first. This assertion is not supported by figure 27, the brightest portions of which, the portions that would the longest be seen as reflection grew steadily feebler, coincide with strong nitrogen bands. In this connection, however, it should be remembered that accurate wave-length measurements, and therefore positive identification of the lines of lighting spectra, is not possible, owing to the small dispersion or separation of the lines on all such negatives so far reported.

Duration.—The duration of the lightning discharge is exceedingly variable, ranging from 0.0002 second for a single flash to, in rare cases, even a full second or more for a multiple flash consisting of a primary and a series of sequent flashes. On rare occasions a dischare of long duration appears *to the eye* to be steady like a glowing solid. Possibly the best measurements of the shorter intervals were made by De Blois (17) with the aid of a high-frequency oscillograph. He found the durations of 38 single peaks, averaging 0.00065 second, to range from 0.0002 second to 0.0016 second. Flashes that last as long as a few tenths or even a few hundredths of a second are almost certainly multiple, consisting of a succession

of apparently individual discharges occurring at unequal intervals. Occasionally a practically continuous discharge of varying intensity, but all the time strong enough to produce luminosity, will last a few hundredths of a second.

It must be remembered that the duration of even a single discharge and the length of time to complete the circuit, or ionize a path, from cloud to earth, say, are entirely different things. The latter seems usually (rocket and ball lightning may furnish exceptions) to be of exceedingly short duration, while the former depends upon the supply of electricity and the ohmic resistance directly and upon the potential difference inversely.

Discharges direct, not alternating.—Years ago some one for some reason or other, or for no reason, made the statement that the lightning flash is alternating and of high frequency, like the discharge of a Leyden jar, and forthwith, despite the fact that all evidence is to the contrary, it became a favorite dogma of the textbook, passed on unquestioned from author to author and handed down inviolate from edition to edition. There often are a number of successive discharges in a fraction of a second, as photographs taken with a revolving camera show, but they are not only along the same path but also in the same direction. This is obvious from the fact that when the side branches persist, as in figure 26, through two or more partial or sequent discharges, they are always turned in the same direction. It is also proved by the direct evidence of the oscillograph (**18**).

In the case of each separate discharge also the direction seems constant. It may vary in strength, or pulsate, but, apparently, it does not alternate. There are several reasons for concluding that lightning discharges are direct and not alternating, of which the following cover a wide range and probably are the best:

a. Lightning operates telegraph instruments. If the discharge were alternating it would not do so.

b. At times it reverses the polarity of dynamos. This requires a direct and not a high-frequency alternating discharge.

c. The oscillograph (**19**) shows each surge or pulsation, as well as the whole flash, to be unidirectional.

d. The relative values of the ohmic resistance, the self-induction, and the capacity, in the case of a lightning discharge, appear usually, if not always, to be such as to forbid the possibility of oscillations.

It has been shown that whenever the product of the capacity by the square of the resistance is greater than four times the self-induction, or, in symbols, that whenever

$$CR^2 > 4L$$

oscillations are impossible. Undoubtedly all these terms vary greatly in the case of lightning discharges, but R, presumably, is always sufficiently large to maintain the above inequality and therefore absolutely to prevent oscillations.

Possibly a calculation giving roughly the numerical order of the terms involved would be helpful. For this purpose assume a cloud whose undersurface is circular with a radius of 3 kilometers, and whose height above the ground is 1 kilometer, and let there be a discharge from the center of the cloud base straight to the earth: Find a probable value for the self-induction and capacity, and from these the limiting value of the resistance to prevent oscillations, or the value of R in the equation

$$CR^2 = 4L.$$

To find L we have the fact that the coefficient of self-induction is numerically equal to twice the energy in the magnetic field per unit current in the circuit, and the further fact that per unit volume this energy is numerically equal to $H/8\pi$, in which H is the magnetic force. Let a be the radius of the lightning path and assume the current density in it to be uniform. Let b be the equivalent radius of the cylinder, concentric with the lightning path, along which the return or displacement current flows. In this case the energy W of the magnetic field per centimeter length of the discharge is given by the equation

$$W = \log_e \frac{b}{a} + \frac{1}{2}.$$

Let $b=2$ kilometers and $a=5$ centimeters. Then $W = \log_e 4\times10^4 + \frac{1}{2} = 11$, approximately. Hence the energy of the magnetic field per unit current for the whole length, 1 kilometer, of the flash is represented by the equation

$$W10^5 = 11\times10^5,$$

hence the self-induction $= 22\times10^5 = 22\times10^{-4}$ henry.

To find C we shall assume a uniform field between the cloud and the earth. As a matter of fact this field is not uniform, and the calculated value of C, based upon the above assumption, is somewhat less than its actual value. Assuming, then, a uniform field we have

$$C = \frac{a}{4\pi d} = \frac{\pi 9\times10^{10}}{4\pi\times10^5} = 225\times10^3 = 25\times10^{-8} \text{ farad, about.}$$

Hence, substituting in the equation

$$CR^2 = 4L,$$

we get

$$R = 190 \text{ ohms per kilometer, approximately.}$$

Neither a, the radius of the lightning path, nor b, the equivalent radius of the return current is accurately known, but from the obviously large amount of suddenly expanded air necessary to produce the atmospheric disturbances incident to thunder it would seem that 1 centimeter would be the minimum value for a. Also, from the size of thunder clouds, it appears that 10 kilometers would be the maximum value for b.

On substituting these extreme values in the above equations, we get

$$R = 200 \text{ ohms per kilometer, roughly.}$$

From the fact that C varies inversely and L directly as the altitude of the cloud it follows that, other things remaining equal, the height of the cloud has no effect on the value of R per unit length.

If the altitude is kept constant and the size of the cloud varied C will increase directly as the area, and L will increase directly as the natural logarithm of the equivalent radius of the cylinder of return current. Assuming the area of the cloud base to be 1 square kilometer, which certainly is far less than the ordinary size, and computing as above we find

$$R = 850 \text{ ohms per kilometer, roughly.}$$

Again, assuming the base area to be 1,000 square kilometers, an area far in excess of that of the base of an ordinary thunderstorm cloud, we find

$$R = 35 \text{ ohms per kilometer, roughly.}$$

It would seem, therefore, that a resistance along the lightning path of the order of 200 ohms per kilometer, or 0.002 ohm per centimeter, would suffice, in most cases, absolutely to prevent electrical oscillations between

cloud and earth. In reality the total resistance includes, in addition to that upon which the above calculations are based, the resistance in parallel of the numerous feeders or branches within the cloud itself. In other words, the assumption that the resistance of the condenser plates is negligible may not be strictly true in the case of a cloud. Nor is this the only uncertainty, for no one knows what the resistance along the path of even the main discharge actually is; though, judging from the resistance of an oscillatory electric spark (**20**), it, presumably, is much greater than the calculated limiting value; and if so, then lightning flashes, as we have seen, must be unidirectional and not alternating.

Length of streak.—The total length of a streak of lightning varies greatly. Indeed the brush discharge so gradually merges into the spark and the spark into an unmistakable thunderbolt that it is not possible sharply to distinguish between them, nor, therefore, to set a minimum limit to the length of a lightning path. When the discharge is from cloud to earth the length of the path is seldom more than 2 to 3 kilometers, but, in the case of low-lying clouds, may be much less, and especially so when they envelop a mountain peak.

On the other hand, when the discharge is from cloud to cloud the path generally is far more tortuous and its total length much greater, amounting at times to 10, 15, and even 20 kilometers.

Discharge, where to where?—As already explained, lightning discharges may be from cloud to earth, from one part to another of the same cloud, or from cloud to cloud. But since the great amount of electrical separation, without which the lightning could not occur, takes place within the rain cloud, it follows that this is also likely to be the seat of the steepest potential gradients. Hence it would appear that lightning must occur most frequently between the lower and the upper portions of the same cloud, and this is fully supported by observations. The next in frequency, especially in mountainous regions, is the discharge from cloud (lower portion) to earth, and the least frequent of all, ordinarily, those that take place between one and another entirely independent or disconnected clouds.

Explosives effects.—The excessive and abrupt heating caused by the lightning current explosively and greatly expands the column of air through which it passes. It even explosively vaporizes such volatile objects as it may hit that have not sufficient conductivity to carry it off. Hence, chimneys are shattered, shingles torn off, trees stripped of their bark or utterly slivered and demolished, kite and other wire fused or volatilized, holes melted through steeple bells and other large pieces of metal, and a thousand other seeming freaks and vagaries wrought.

Many of the effects of lightning appear at first difficult to explain, but, except the physiological and, probably, some of the chemical, all depend upon the sudden and intense heating along its path.

Chemical effects.—As is well known, oxides of nitrogen and even what might be termed the oxide of oxygen, or ozone, are produced along the path of an electric spark in the laboratory. Therefore one might expect an abundant formation, during a thunderstorm, of these same compounds. And this is exactly what does occur, as observation abundantly shows. It seems probable, too, that some ammonia must also be formed in this way, the hydrogen being supplied by the decomposition of raindrops and water vapor.

In the presence of water or water vapor these several compounds undergo important changes or combinations. The nitrogen peroxide (most stable of the oxides of nitrogen) combines with water to produce both nitric and nitrous acids; the ozone with water gives hydrogen peroxide and sets free oxygen; and the ammonia in the main merely dissolves, but probably also to some extent forms caustic ammonia and hydrogen. Symbolically the reactions seem to be as follows:

$$2NO_2 + H_2O = HNO_3 + HNO_2.$$
$$O_3 + H_2O = H_2O_2 + O_2.$$
$$2NH_3 + 2H_2O = 2NH_3OH + H_2.$$

The ammonia and also both the acids through the production of soluble salts are valuable fertilizers. Hence, wherever the thunderstorm is frequent and severe, especially, therefore, within the tropics, the chemical actions of the lightning may materially add, as has recently been shown (**21**), to the fertility of the soil and the growth of crops.

Danger.—It is impossible to say much of value about the danger from lightning. Generally it is safer to be indoors than out during a thunderstorm, especially if the house has a well-grounded metallic roof. If outdoors it is far better to be in a valley than on the ridge of a hill, and it is always dangerous to take shelter under a tree—the taller the tree, other things being equal, the greater the danger. Some varieties of trees appear to be more frequently struck, in proportion to their numbers and exposure, than others, but no tree is immune. It seems that, in general, the trees most likely to be struck are those that have either an extensive root system, like the locust, or deep tap roots, like the pine, and this for the very obvious reason that they are the best grounded and therefore offer, on the whole, the least electrical resistance.

Finally, if one has to be outdoors and exposed to the danger of a violent thunderstorm it is advisable, so far as danger from the lightning is concerned, to get soaking wet, because wet clothes are much better conductors, and dry ones poorer, than the human body. In extreme cases it might even be advisable to lie flat on the wet ground.

As just implied, the contour of the land is an important factor in determining the relative danger from lightning because, obviously, the chance of a cloud-to-earth discharge, the only kind that is dangerous, varies inversely as the distance between them. Hence thunderstorms are more dangerous in mountainous regions, at least in the higher portions, than over a level country. For this same reason also, distance of cloud to earth, there exists on high peaks a level or belt of maximum danger, the level, approximately of the base of the average cumulus cloud. The tops of the highest peaks are seldom struck, simply because the storm generally forms and runs its course at a lower level.

Clearly, too, for any given section the lower the cloud the greater the danger. Hence a high degree of humidity is favorable to a dangerous storm, partly because the clouds will form at a low level and partly because the precipitation will be abundant. Hence, too, a winter thunderstorm, because of its generally lower clouds, is likely to be more dangerous than an equally heavy summer one.

The ceraunograph.—Various instruments, based upon the principles of "wireless" receivers, have been devised for recording the occurrence of lightning discharges. Of course the sensitiveness of the instrument, the distance and the magnitude of the discharge all are factors that affect the record, but by keeping the sensitiveness constant, or nearly so, it is possible with an instrument of this kind to estimate the approximate distance, progress, and to some extent even the direction of the storm. Nevertheless there does not appear to be much demand for

this information, and therefore at present the ceraunograph is but sparingly used.

Thunder.—For a long while no one had even a remotely satisfactory idea in regard to the cause of thunder, and it is not a rare thing even yet to hear such a childish explanation as that it is the noise caused by the bumping or rubbing of one cloud against another.

As above explained, because of the sudden and intense heating due to the lightning discharge the air column through which it passes is so greatly and so abruptly expanded as to simulate in every detail a violent explosion, and therefore to send out from every portion of its path a steep compression wave, which, of course, is the real physical cause of the thunder. The expansion, obviously, is followed by a cooling and contraction, but though this action is rapid it probably is not nearly rapid enough to have anything to do with the production of thunder, though many have suggested it as the whole cause.

Rumbling.—Probably the most distinctive characteristic of thunder is its long-continued rumbling and great variation in intensity. Several factors contribute to this peculiarity, among them:

Inequalities in the distances from the observer to the various portions of the lightning's path. Hence the sound, which ordinarily travels about 330 meters per second in the air, will not all reach him at the same time, but continuously over an appreciable interval of time.

Crookedness of path. Because of this condition it often happens that sections of the path here and there are, each through its length, at nearly the same distance from the observer or follow roughly the circumferences of circles of which he is the center, while other portions are directed more or less radially from him. This would account for, and doubtless in a measure is the correct explanation of, some of the loud booming effects or crashes that accompany thunder.

Succession of discharges. When, as often happens, several discharges follow each other in rapid succession there is every opportunity for all sorts of irregular mutual interference and reinforcement of the compression waves or sound impulses they send out.

Reflection. Under favorable conditions the echo of thunder from clouds, hills, and other reflecting objects certainly is effective in accentuating and prolonging the noise and rumble. But the importance of this factor generally is greatly overestimated, for ordinarily the rumble is substantially the same whether over the ocean, on the prairies, or among the mountains.

Distance heard.—The distance to which thunder can be heard seldom exceeds 25 kilometers, while ordinarily, perhaps, it is not heard more than half so far. To most persons, familiar with the great distances to which the firing of large cannon is still perceptible, the relatively small distances to which thunder is audible is quite a surprise. It should be remembered, however, that both the origin of the sound and often the air itself as a sound conductor are radically different in the two cases. The firing of cannon or any other surface disturbance is heard farthest when the air is still and when, through temperature inversion or otherwise, it is so stratified as in a measure to conserve the sound energy between horizontal planes. Conversely, sound is heard to the least distance when the atmosphere is irregular in respect to either its temperature or moisture distribution, or both, for these conditions favor the production of internal sound reflections and the dissipation of energy. Now the former or favorable conditions occasionally obtain during the production of ordinary noises, including the firing of cannon, but never obtain during a thunderstorm. In fact, the thunderstorm is especially likely itself to establish the second set of the above conditions, or those least favorable to the far carrying of sound.

Then, too, when a cannon, say, is fired the noise all starts from the same place, the energy is concentrated, while in the case of thunder it is stretched out over the entire length of the lightning path. In the first case the energy is confined to a single shell; in the second it is diffused through an extensive volume. It is these differences in the concentration and the conservation of the energy that cause the cannon to be heard much farther than the heaviest thunder, even though the latter almost certainly produces much the greater total atmospheric disturbance.

Normal atmospheric electricity.—The only reason for mentioning normal atmospheric electricity in connection with thunderstorms is to emphasize the fact that, contrary to what many suppose to be the case, there is but little relation, in the sense of cause and effect, between these two phenomena. Thus while the difference in electrical potential between the surface of the earth and a point at constant elevation is roughly the same at all parts of the world, the number and intensity of thunderstorms vary greatly from place to place. Further, while the potential gradient at any given place is greatest in winter the number of thunderstorms is most frequent in summer, and while the gradient, in the lower layer of the atmosphere, at many places, usually is greatest from 8 to 10 o'clock, both morning and evening, and least at 2 to 3 o'clock p. m. and 3 to 4 o'clock a. m., no closely analogous relations hold for the thunderstorm.

Probably the most interesting conclusion in regard to normal atmospheric electricity so far drawn from observation and experiment is this: That the earth everywhere, land and water and from pole to pole, is a negatively charged sphere of practically constant surface density, surrounded by an atmosphere so conducting that it is constantly carrying away a current that amounts on the whole to about 1,000 amperes.

Where the supply of negative electricity comes from that keeps the surface of the earth on the whole negatively charged in spite of this steady great loss, or how the outgoing current is compensated, no one knows. Rain does not help matters for, as we have seen, that is prevailingly positive, whereas we need, to compensate the loss, to bring back negative electricity and a great deal of it. Neither, so far as known, is compensation supplied by means of the lightning, for, in the great majority of cases, this, too, is positive from cloud to earth. And so the puzzle remains. As Simpson (22) puts it:

> A flow of negative electricity takes place from the surface of the whole globe into the atmosphere above it, and this necessitates a return current of more than 1,000 amperes; yet not the slightest indication of any such current has so far been found, and no satisfactory explanation for its absence has been given.

Much more, of course, might be said on this subject, for it is a big one on which many have labored, but perhaps the above is sufficient for the purpose of this final section, namely, to show that, contrary to opinions often held, there is no obvious and close relation between the thunderstorm and normal atmospheric electricity; that, according to our best evidence, they are distinct and independent phenomena.

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SECTION III.—FORECASTS.

STORMS AND WARNINGS FOR JUNE.

By H. C. FRANKENFIELD, Professor of Meteorology.

[Dated, U. S. Weather Bureau, Washington, July 3, 1914.]

Storm warnings were displayed on June 6, 23, 26, and 27.

The warnings on the 6th were displayed on the California coast from Point Lobos to Eureka, on account of the approach of a marked storm toward the north Pacific coast. The warnings of the 23d were displayed on the California coast at Eureka only.

On the morning of the 26th there was a storm of well-defined character central over western South Dakota and, after special observations had been called for, northeast storm warnings were ordered on Lake Superior from Duluth to Marquette and on Lake Michigan at Escanaba. The storm continued to move eastward with about the same intensity and on the evening of the 26th southeast storm warnings were ordered on the west shore of Lake Michigan from Green Bay to Plum Island; by this time high northeast winds were blowing over extreme western Lake Superior. On the morning of the 27th the storm was over southern Minnesota and southeast and southwest storm warnings were ordered over the balance of the upper Lakes and also at Detroit and Toledo. At 3 p. m. of the 27th warnings were continued over western Lake Superior and at Escanaba, and at 10 p. m. southwest warnings were ordered for the balance of the lower Lakes. The storm at this time was central over Lake Michigan, with slightly increased intensity and was moving eastward. High winds characterized the progress of this storm, except over the eastern lower Lake region and the Atlantic coast. After reaching the lower Lake region the storm diminished in intensity and passed off the New England coast during the 30th only as a moderate depression. The highest winds of the storm were experienced on western Lake Superior, Duluth reporting a maximum velocity of 60 miles per hour from the northeast during the night of June 26–27; over the remaining portions of the Lakes the winds were not nearly so high.

Small-craft warnings were also occasionally ordered during the month on the Lakes, but their display was without any features of interest.

Frost warnings were ordered on the 1st, 5th, 6th, 10th, 15th, 16th, 19th, and 20th. The frost warnings on the 1st were ordered for the cranberry districts of Wisconsin, there being at the time a cold high-pressure area central over Minnesota and eastern South Dakota. Warnings for the 5th were widely scattered. The high-pressure area that had moved southward from the Hudson Bay country following a storm from the west was accompanied by a decided fall in temperature, and on the morning of the 5th frost warnings were ordered for the Cape Cod cranberry districts. At the same time pressure was rising rapidly in the North Pacific States following a low area that at the time was over the Canadian Northwest, and frost warnings were ordered for eastern Oregon, southern Idaho, western Montana, and northwestern Wyoming. On the following morning heavy frost occurred in portions of Idaho, but over the remaining sections for which frost had been forecast none occurred on account of the persistence of cloudy weather with rains. On the 10th the increased pressure over the northern Plateau indicated frost in that section for the following morning, and warnings were accordingly ordered, but here again clouds intervened and prevented the formation of the frost. On the 15th strong high pressure over South Dakota again necessitated warnings for the cranberry marshes of Wisconsin and frost occurred on the following morning over southern Wisconsin and upper Michigan. The frosts in Michigan had not been anticipated, but they were so light that no damage was caused. As this high area continued to move eastward, frost warnings were ordered on the 16th for northern New England, the interior of Massachusetts and New York, the cranberry marshes of New Jersey, and the mountain districts of Maryland and Virginia. These forecasts were not generally verified although frost occurred in scattered localities. On the 19th a high area from Manitoba moving southward, following a depression over the upper Mississippi Valley and the Lake region, indicated quite low temperatures for the following morning over the upper Lakes, and frost warnings were accordingly issued for the general frosts that occurred on the morning of the 20th. Frost warnings were also issued on the 20th for the cranberry districts of New England and New Jersey and for the interior of New England and New York, but they failed of verification on account of the rapid movement of a disturbance from the west.

There were several special weather features during the month. The first was the cold wave with attendant low pressure that prevailed over the districts west of the Rocky Mountains from the 2d to the 8th, inclusive. During this time pressure remained steadily low with temperatures in some localities as much as 30° below the seasonal average. Snow occurred on the morning of the 5th in northern Nevada and on the morning of the 6th in northern Utah. Freezing temperatures occurred quite generally during the week and it was not until after the morning of the 9th that the temperatures rose with clearing weather and the approach of a high-pressure area from the North Pacific coast. The second unusual feature was the heavy rainfall over the greater portion of South Dakota during the first two weeks of the month. During this time the Weather Bureau station at Huron, S. Dak., reported 11.30 inches of rain. The third feature was the occurrence of a severe drouth for the first three weeks of the month over the interior districts south of the Ohio River and in Maryland and Virginia. During the fourth week, however, a storm period set in, bringing with it frequent and abundant rains over Maryland, the District of Columbia, Virginia, and portions of West Virginia. Over the remainder of the dry area, however, the rains were not of much consequence. The fourth feature of the month's weather was the occurrence and persistence of a hot wave over the central, southern, and southwestern portions of the country. The hot wave in the South was practically continuous after the 6th of the month, except for a few days during the second decade, and many records for the month were equaled or exceeded over the central portion of the country. There was a hot wave from the 6th to the 11th, inclusive, and another from the 14th to the 27th, inclusive, over the central portion of the country during which time records

were equaled or exceeded. Over the eastern districts the hot waves were not so prolonged, but there were two well-marked periods from the 10th–12th, and another from the 23d–26th, both inclusive, during which records were also equaled and exceeded in southern Virginia.

NORTHERN HEMISPHERE PRESSURE DISTRIBUTION.

Over the Aleutian Islands, as indicated by the reports from Dutch Harbor, low pressure prevailed during the first half of the month with a marked minimum on the 4th and quite well-marked depressions on the 14th and 16th. After this time pressure ruled high, although not decidedly so, except from the 27th to the 29th. Over Alaska there were the usual alternations of high and low pressures with neither predominating to any large extent. The greatest depression occurred at Nome on the 12th and the highest pressure on the 20th, also at Nome.

Over the United States west of the Rocky Mountains there was a low-pressure period lasting for nearly 10 days without any great storm movement. The low pressure was then followed by a period of high pressure, which prevailed quite generally until the end of the month, except between the 18th and 23d, when the barometer was moderately low. East of the Rocky Mountains there was a more regular alternation of high and low pressure areas, but with high pressure prevailing more uniformly over the southern districts, with a result that a hot wave prevailed during most of the month south of the Ohio River. The storms were not of great magnitude, although the extreme northwestern depression of the 2d became a severe storm by the time it had reached the Newfoundland coast. Over the North Atlantic Ocean, as indicated by reports from Bermuda, Turks Island, and the Azores, high pressure ruled almost uniformly.

Over Iceland and the British Isles high pressure prevailed during the first half of the month and low pressure thereafter, as a rule, with a marked minimum over Iceland on the 26th. At Spitzbergen high pressure also prevailed throughout the month. Over continental Europe the pressure was quite low during the first week of the month and high thereafter, as a rule, except over southern Russia, where it was low throughout the month, except for one or two days about the middle of the month. Over Siberia the distribution was irregular, but with a tendency toward moderately high pressure during the first half of the month, and low pressure during the second half. The only decided depressions occurred at Tomsk on the 18th and at Irkutsk on the 19th and Nertchinsk on the 28th.

Over eastern China and Japan conditions were somewhat more regular with the usual alternations of moderately high and low pressure areas, except that quite low pressure ruled over Japan from the 5th to the 10th.

Over the North Pacific Ocean, as indicated by reports from Honolulu, pressure slightly below normal prevailed almost uniformly, except during the first five days of the month.

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, JUNE, 1914.

By HENRY E. WILLIAMS, Meteorologist, Temporarily in charge of River and Flood Division.

[Dated, Washington, D. C., July 29, 1914.]

THE ANNUAL RISE IN THE COLUMBIA RIVER.

Mr. E. A. Beals, District Forecaster, in charge of the Columbia River district reports:

During the annual rise of the Columbia River this year no flood stages were reached except at Vancouver, Wash., and Portland, Oreg. Portland is on the Willamette River, and the rise in that stream is due to backwater from the Columbia River. Ample warnings were given and no losses occurred in consequence of this flood.

The fact that no great rise would occur this year in the Columbia River was announced in the Snowfall Bulletin for the month of March, 1914, which read as follows: "From the following reports relating to the winter's snowfall in the Columbia River Drainage Area and the amount remaining in the mountains at the end of March, no very high water can be expected in the lower Columbia River this season, unless unusual temperature conditions prevail in May."

The following table shows the stages reached at the various stations along the Columbia River during the rise of 1914:

TABLE 1.—*Annual rise of the Columbia River, 1914.*

Stations.	Rivers.	Flood stage.	Highest stages, 1914.	
			Stage.	Date
		Feet.	*Feet.*	
Kamiah, Idaho	Clearwater	12	11.9	May 18
Weiser, Idaho	Snake	14	9.6	{May 25 May 26
Lewiston, Idaho	Clearwater	22	13.3	May 25
Riparia, Wash	Snake	30	13.3	Do.
Bonners Ferry, Idaho	Kootenai	26	23.8	June 6
Newport, Idaho	Pend Oreille	16	13.1	May 31
Northport, Wash	Columbia	40	23.9	June 21
Wenatchee, Wash	do	40	32.9	Do.
Kennewick, Wash	do	25	14.7	May 27
Umatilla, Oreg	do	25	18.3	May 26
The Dalles, Oreg	do	40	29.6	May 27
Cascade Locks, Oreg	do	46	22.7	Do.
Vancouver, Wash	do	15	17.2	May 28
Portland, Oreg	do	15	16.8	May 29

The Columbia and the Colorado are preeminently the two rivers in the United States which have a marked rise each year due to melting snow. The volume of water that passed down the Colorado this year was somewhat more than the usual amount, as may be seen from the report of District Forecaster Brandenburg, which follows:

COLORADO RIVER.

Remarkably high stages prevailed in the Colorado River during June. In the streams forming the Colorado the stages, as a rule, were not quite so high as occurred during June, 1909, following a winter of exceptionally heavy snowfall, but at one station on the trunk stream, Topock, near Needles, the highest stage of record, 22.6 feet, occurred. At Yuma, near the mouth, however, the highest stage, 29 feet, was 1.7 feet lower than occurred in 1909.

The highest stages of the season occurred at the beginning of the month in the Grand River and its tributaries, in the upper Gunnison and the San Juan. By the 4th a steady fall was under way, which lasted until the 10th. The stages reached during the rise that followed were generally about 1 foot below those of the early part of the month. A steady decline set in at the beginning of the third decade. In the Green River the season's crest occurred on the 5th and 9th; from the 10th to the 14th the fall was marked, but throughout the latter half of the month the decline was relatively slight.

In the trunk stream at Topock the highest stage was reached on the 9th; a fall of 11 feet occurred during the next 7 days. At Yuma the highest stage occurred on the 14th and 15th.

Timely warnings, in some cases 8 to 10 days in advance, were sent to localities likely to be injured. Great damage was prevented by the protective measures taken.

ARKANSAS RIVER.

The average discharge of the Arkansas was the greatest for June in the last five years. At Salida the highest stage was slightly lower than in 1912, but at Pueblo and Fort Lyon the stages reached were the highest in years. No material damage resulted from high water.

THE RIO GRANDE RIVER.

In the Rio Grande River the discharge was close to the average, while the highest stages reached were lower than usual.—*F. H. Brandenburg, District Forecaster.*

RIVERS IN TEXAS.

On June 1 most of the streams of the district were still above flood stage in their lower portions from the heavy rains of May, but were falling rapidly, and, as a rule, were at low-water mark by June 29 or 30. The fall in the Colorado was interrupted by a sharp, though not serious, rise which moved downstream from Ballinger on the 16th and reached Columbus on the 21st, flooding some of the lowlands in that section and at points below. The Brazos

TABLE 2.—*Maximum stages of Texas rivers during June, 1914.*

Stations and rivers.	Highest.	Date.
Rio Grande:	*Feet.*	
Eagle Pass	12.9	20
Laredo	10.0	21
Rio Grande	14.3	22
Mission	20.4	1
Guadalupe:		
Gonzales	17.3	2
Victoria	23.1	1
Colorado:		
Ballinger	8.0	16
Marble Falls	15.5	19
Austin	16.5	20
Columbus	33.2	2
Brazos:		
Brazos	8.8	1
Kopperl	10.6	1
Waco	18.7	1
Valley Junction	39.0	1
Hempstead	40.4	4
Booth	40.6	7
Trinity:		
Bridgeport	4.8	1
Dallas	32.2	1
Long Lake	40.0	5
Riverside	25.2	12*
Liberty	27.7	1*
Neches:		
Rockland	21.1	1*
Beaumont	9.8	1*
Sabine:		
Logansport, La	22.9	1
Merryville, La	17.6	1
Orange	5.2	1

*Also on subsequent dates.

rise reached Hempstead on the 4th and Booth on the 7th. The Trinity was flooded in its upper portion from June 1 to 6, and in its lower portion from June 1 to 10. No damage was reported from the high water in June, but additional damage reported from the May freshets was: Guadalupe Valley, $21,000; Trinity Valley, $52,000; and railroads, $77,000.

Table 2 shows the highest stages recorded at the various river stations during the month.—*B. Bunnemeyer, Section Director.*

DUBUQUE RIVER DISTRICT.

A moderate June flood in the Wisconsin River below Wausau, Wis., and in the Mississippi River from Dubuque, Iowa, to La Crosse, Wis., occurred during the first half of the month as the result of very heavy rains in a portion of northern Wisconsin on June 3–4.

The rainfall within 24 hours, beginning at about 5 a. m. of the 3d and ending about 4 a. m. of the 4th, was 6.08 inches at Medford, Wis. It was probably heavier at Knowlton, but, unfortunately, the rain gage was blown over by the storm and an accurate measurement of rainfall was not obtained. The rainfall within 24 hours was 2.92 inches at Merrill, Wis.; 2.64 inches at Wausau, Wis.; 2.48 inches at Antigo, Wis.; 3 inches at Grand Rapids, Wis. The rainfall on June 3–4 was 3.55 inches at Marshfield, Wis., and 3.43 inches at Stevens Point, probably within a period of 24 hours.

There was no important rise at and above Wausau, Wis. The stage of water at 5 p. m. of June 3 at Knowlton, Wis., was 2.7 feet. The river began to rise rapidly during the night of the 3d–4th, reaching a stage of 5.8 feet at 5 a. m. of the 4th; 12.2 feet at 5 p. m. of the 4th; and a maximum stage of 16.8 feet at 8.45 a. m. on the 5th. The greatest rise in 24 hours was about 10 feet. The only important damage on the Wisconsin River occurred at Knowlton, and is estimated as follows: Four thousand dollars to bridges; $500 to highways; $3,000 to growing crops on lowlands; $200 from suspension of business; total, $7,700.

At Grand Rapids, Wis., the river rose from 3.3 feet at 7 a. m. of the 4th to a maximum of 12 feet soon after midnight of the 6th–7th. At this place numerous cellars and basements of business houses were flooded, but the goods were removed therefrom, as merchants had sufficient warning of the flood. The main loss was about $500, due to suspension of business.

There was no loss of much importance below Grand Rapids, Wis., except to wild hay, since live stock and other property was removed from lowlands and islands as the result of warnings issued a number of days in advance of the flood crest. Hundreds of acres of wild hay, growing on lowlands, was spoiled or damaged. The postmaster at Avoca, Wis., states: "One thousand tons of wild hay, valued at $4 per ton, was spoiled."

HIGH WATER IN THE MISSISSIPPI RIVER.

High water in the Mississippi was due chiefly to floods on the Wisconsin and Black Rivers. The water at Lansing, Iowa, rose 3.2 feet in 5 days, reaching a stage of 10.2 feet on the 13th. At Prairie du Chien it rose 5.2 feet in 7 days, reaching 12.3 feet on the 16th; at Dubuque it rose 5.4 feet in 7 days, reaching 13.4 feet on the 18th.

The chief damage was to crops on lowlands and islands, practically all of which were covered with water from 1 foot to 3 feet. The exact loss is difficult to determine, but probably 1,500 acres or more of growing corn and perhaps 200 acres of growing miscellaneous crops between Dubuque and La Crosse were inundated; value about $50,000.

The total loss for the Dubuque district, including the Mississippi and Wisconsin Rivers, may be summarized as follows: Loss to bridges, highways, etc., $6,500; loss of prospective crops, $60,000; loss of live stock, $200; loss due to suspension of business, $8,000; total, about $75,000.

Warnings were issued a week to 10 days in advance of the flood crest, and a small acreage was saved by temporary dikes. In this connection the following extract from a letter from Mr. W. S. Bickel, of the Bickel Hydro-Electric Construction Co., Cedar Rapids, Iowa, is of interest:

> At the time of the flood I was working along the bottom lands in the upper Mississippi Valley. The river stages were forecasted accurately, and in case the owners of land had been familiar with the elevation of their bottom lands, they might have saved large areas from inundation by building temporary dikes, not over 2 feet high. Several fields which came under my observation were covered just enough to drown the corn.

Much live stock was removed from lowlands and islands in time to prevent loss. A large quantity of wood and other property was also removed. The money value of the property saved by warnings in the Dubuque River district is estimated to be about $25,000.—*J. H. Spencer, Local Forecaster.*

FLOODS IN THE WICHITA RIVER DISTRICT.

The Arkansas River was high generally throughout the Wichita River district between June 16 and 25, 1914, and exceeded flood stage at points from Dodge City to Ellinwood, Kans. The river at Dodge City exceeded its flood stage of 5 feet on the 17th, reaching a crest stage of 5.8 feet at 4:20 p. m. on that date, and receded below flood stage by 8 a. m. on the 18th. The river overflowed its banks at Kinsley on the 19th, reaching a crest stage of about 6 feet on that date, and receded below flood stage on the 21st. The river overflowed its banks in the vicinity of Ellinwood, on the 19th, reaching a crest stage of 6.8 feet on the same day and receding below flood stage on the 20th. The flood stages for the last two points are not known with definiteness, but are probably about 5 feet at Kinsley and about 6 feet at Ellinwood. Reports indicate that the river, though high, was confined within its banks at points below Ellinwood. The high water reached Wichita on the 20th, with a crest stage of +1.6 feet at 7 p. m. The river receded to a stage of 0.0 foot at 7 a. m. on the 25th. The crest at Wichita was probably about 6.6 feet above the average stage of the river during the past winter.—*S. P. Petersen, Observer.*

RIVERS ELSEWHERE.

During the month flood stages were slightly exceeded in the rivers of central and northern California, in the James River in South Dakota, the St. Croix River in Minnesota, the Yellowstone River in Montana, and the Grand River in Missouri, but no damages were reported.

FIG. 2.—Mount Lowe, Cal., during the rain of February 20, 1914.

MEAN LAKE LEVELS DURING JUNE, 1914.

The following data are as reported in the U. S. Lake Survey "Notice to Mariners" dated Detroit, Mich., July 6, 1914:

Data.	Lakes.			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during June, 1914:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.49	580.60	573.04	246.91
Above or below—				
Mean stage of May, 1914	+ 0.16	+ 0.28	+ 0.13	− 0.04
Mean stage of June, 1913	+ 0.13	− 0.60	− 0.82	− 1.11
Average stage for June, last 10 years	+ 0.19	− 0.47	+ 0.02	− 0.23
Highest recorded June stage	− 0.94	− 3.00	− 1.48	− 1.72
Lowest recorded June stage	+ 1.25	+ 0.70	− 1.47	+ 2.02
Probable change during July, 1914	+ 0.2	+ 0.10	− 0.1	− 0.1

FLOOD STUDIES AT LOS ANGELES.[1]

By Ford A. Carpenter, Local Forecaster.

[Dated, Weather Bureau, Los Angeles, Cal., Apr. 8, 1914.]

[An address before the southern California association of members of the American Society of Civil Engineers, Los Angeles, Cal., Apr. 8, 1914.]

Introduction.

The rainstorm of February 18-21, 1914, caused the most damaging but not the greatest flood in the history of Los Angeles. Railway and street traffic were interrupted for a period exceeding 24 hours, bridges and roadbeds were destroyed, the harbor was silted, and some ranches and orchards swept bare. The property loss probably exceeded $3,000,000. This was offset many times over by the great amount of good this storm did in filling the depleted mountain reservoirs, raising the level of the valley ground water, and amply soaking the hundreds of thousands of acres of agricultural land in the Los Angeles district.

If such floods were matters of rare occurrence, and the resulting damage could not be prevented, then the monetary loss and the temporary inconvenience might be forgotten, or the "unusual" weather remembered as being among the rare occasions in southern California when meteorological conditions were not favorable. But such is not the case, as will be shown by the accompanying tables and charts recording weather conditions since the establishment of the local Weather Bureau station 37 years ago. The object of this present paper is to give some of the contributing causes of these floods in general, and of the last February storm in particular. It is also desired to set forth a brief history of past floods in Los Angeles and detail some of their pertinent features.

As is well known, there is but one reason for the production of rain, viz, condensation of atmospheric moisture far below the saturation point. In southern California this condensation is brought about primarily by the action of the eddying winds in a storm center and the attendant upward deflection of moisture-bearing winds. Owing to the general eastward drift of the earth's atmosphere in these latitudes, the air from the Pacific Ocean reaches us moist and of nearly constant temperature. Precipitation occurs in southern California whenever there is sufficient atmospheric disturbance to expand and cool the moisture-laden winds far below their dew point. This disturbing feature is almost invariably an aerial eddy, the familiar "low" of the weather map. Whenever the path of a low-pressure area extends as far south as latitude 40° N., precipitation results in this portion of the State. The amount of the precipitation is determined generally by the blocking of a ridge of high pressure, which prevents the normal eastward drift of the storm area. It is thus seen that southern California would be practically rainless all of the time instead of more than half the year, were it not for the slight southward deflections of the paths of the northern storms.

An examination of a chart of annual rainfall shows remarkable variations in the amount and distribution of the seasonal fall. The rainfall in southern California is evidently one of the least dependable of meteorological elements. The irregularity of the seasonal rainfall is further shown by the wide difference between the normal annual rainfall of 15.5 inches at Los Angeles and the extremes of 5.6 inches (1898–99) and 38.2 inches (1883–84). As it is, rain occurs only during a fraction of the year. Los Angeles has an average of but 16 days with a quarter of an inch or more of rain and only 5 days with an inch or more.

Monthly distribution of precipitation.

In figure 1 the rainfall for each month is plotted around a center representing zero and circles are drawn for each inch of rainfall. The radials are the months of the year.

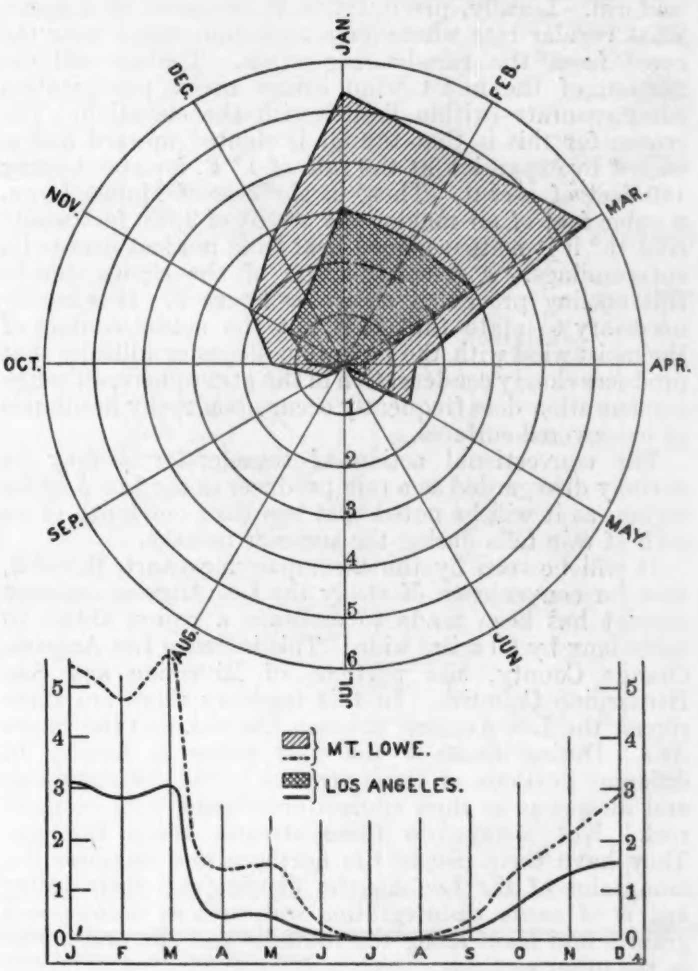

Table of average precipitation at Los Angeles (412 feet) and Mount Lowe, Cal. (3,420 feet), for the 17 complete years 1896–1902, inclusive, and 1904–1913, inclusive (inches).

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Mount Lowe	5.43	4.78	5.66	1.41	1.46	0.31	0.01	0.09	0.39	1.43	2.14	2.87	25.98
Los Angeles	3.08	2.82	3.03	0.42	0.47	0.08	0.01	0.02	0.17	0.71	1.27	1.52	13.60

Fig. 1.—Diagrams and table of annual march of average precipitation at Mount Lowe (3,420 ft.) and Los Angeles, Cal. [alt. 412 ft., A. S. L., 151 ft. above ground.)

[1] The author desires to acknowledge courteous assistance rendered by the local officers of the U. S. Corps of Engineers, the U. S. Forest Service, the manager California Fruit Exchange, and many individuals who contributed precipitation data.

It is the rose of annual rainfall constructed for two homogeneous sets of 17 years. This rose has the advantage of showing continuity in the distribution of rainfall, and is more graphic than the ordinary block system, no matter whether this latter arrangement begins with January or July. This diagram and its accompanying table illustrate two important climatic features—first, the average annual distribution of rainfall, and second, the relationship between rainfall and elevation. Two stations are shown, Los Angeles and Mount Lowe. Mount Lowe was selected because of its proximity to Los Angeles, being within 15 miles of the city and a trifle over 3,000 feet higher. Of course the data cover the same years at both stations. It will be seen from the rain-rose that practically all the precipitation occurs within the months of December, January, February, and March.

Relationship between elevation and precipitation.

A cursory glance at the chart shows a remarkable similarity in the annual distribution as well as in the relative monthly amounts at each station. The rainfall at the Observatory exceeds that in the city by over 60 per cent, although the seasonal distribution is nearly uniform. Locally, precipitation is increased at a somewhat regular rate whenever a mountain range near the coast faces the rain-bearing winds. The upward deflection of the moist wind brings about precipitation commensurate [within limits] with the elevation. The reason for this is that the air is slanted upward and is cooled by expansion at the rate of 1° F. for about every 180 feet of ascent. Thus, in the case of Mount Lowe, a cubic foot of air making the ascent of 3,000 feet would cool 16° if it neither gained heat from nor lost heat to its surroundings. A telephotograph of the clouds due to this cooling process is shown as figure 2. It is hardly necessary to state that it is not the actual contact of the moist wind with the mountain slopes or hillsides that produces cloudy condensation in the atmosphere, although condensation does frequently occur upon rocky headlands or ice-covered surfaces.

The convectional action of thunderstorms may be entirely disregarded as a rain producer in the Los Angeles region, as it will be noted that less than one-tenth of an inch of rain falls during the summer months.

It will be seen by the accompanying chart, figure 3, that for convenience of study the Los Angeles drainage district has been made to embrace a region about 70 miles long by 60 miles wide. This includes Los Angeles, Orange County, and portions of Riverside and San Bernardino Counties. In this territory there are three rivers, the Los Angeles, the San Gabriel, and the Santa Ana. During most of the year water is flowing in different portions of these streams. The rivers appear and disappear as their courses cross sand, silt, loam, or rock. Not always do these streams reach the sea. They have their rise in the northern and northeastern mountains of the Los Angeles district and their valley bed is of easily disintegrating soil, such as decomposed granite and loam along the foothills and silt and adobe in the other sections.

Distribution of precipitation during a typical heavy flood.—The records of precipitation (rain and melted snow) during the storm of February 18–21, 1914, from 42 stations have been collected and tabulated in Table 1. In order to present a picture of the distribution of the precipitation, lines representing areas of from 3 to 19 inches of rainfall have been drawn. The resulting precipitation map (fig. 3) shows that the valleys received on an average of less than 7 inches during these three days, while the moderate elevations of 2,000 feet, with a southwestern exposure, received from 12 to 14 inches. The highest districts received approximately 20 inches.

TABLE 1.—*Total precipitation, February, 1914, in the Los Angeles district. All fell on the 18th, 19th, 20th, and 21st.*

Stations.	Rainfall.	Stations.	Rainfall.
	Inches.		*Inches.*
Avalon	3.45	Palos Verde	3.87
Azusa	13.26	Pasadena	11.44
Bear Valley Dam	10.83	Pomona	9.60
Chino	4.81	Redlands	4.26
Claremont	10.92	Redondo	3.51
Cleghorn Canyon	17.85	Riverside	2.79
Corona	4.31	San Antonio Canyon	12.25
Devil Canyon	8.63	San Bernardino	4.71
East Highlands	4.85	San Dimas	11.29
Fillmore	6.44	San Fernando	8.88
Garvanza	9.41	San Pedro	2.03
Highland	5.68	Santa Monica	5.50
Hollywood	6.75	Sierra Madre	15.56
Long Beach	3.24	Squirrel Inn	16.29
Los Angeles	7.07	Tustin	3.52
Mill Creek	11.10	Valyermo, post office	5.57
Mount Lowe	19.20	Venice	5.16
Mount Wilson	19.40	Ventura	10.21
Orange	3.55	Walnut	6.96
Palm Springs	3.90	Whittier	5.02

The progress of the storm of February 18, 1914.—The Weather Map of the Northern Hemisphere for February 18, 1914, showed an unusually large area of low pressure, extending from eastern Asia to southern California. It was the southern portion of this low area which made its appearance first over the Washington coast. On the 19th and 20th the storm had extended southeastward, although still off the Pacific coast. On the 21st the storm area showed indications of dividing. This separation took place the next day and the storm was central over the western portion of the United States. On the 23d the storm, much reduced in size, occupied the Gulf States. On the 24th it moved along the south Atlantic coast and by the 25th it was off Newfoundland, where it remained stationary. On the 27th it recurved, but by the 28th it was well at sea headed for Iceland, where it was located the next day. This storm, as traced in figure 4, thus traveled halfway around the world from its birth in the Aleutian Islands on February 18 to where it passed beyond the limits of observation on March 1.

History of past floods.

For the past 37 years the local office of the United States Weather Bureau has maintained a fairly detailed account of the occurrence of all floods in the vicinity of Los Angeles. The record is shown in Table 2. Los Angeles has experienced 15 light floods, 18 moderate floods, and 8 heavy floods, and only during 9 of the 37 years has this vicinity been free from these occurrences. The most serious flood in the history of this region was that of 1884; and the largest number of floods in any one year came in 1889, when one occurred in March, another as early as October, and three more in the following December. The records of the United States Engineers show that the Los Angeles Harbor at San Pedro has been silted five times, viz, 1884, 1889, 1890, 1911, and 1914.

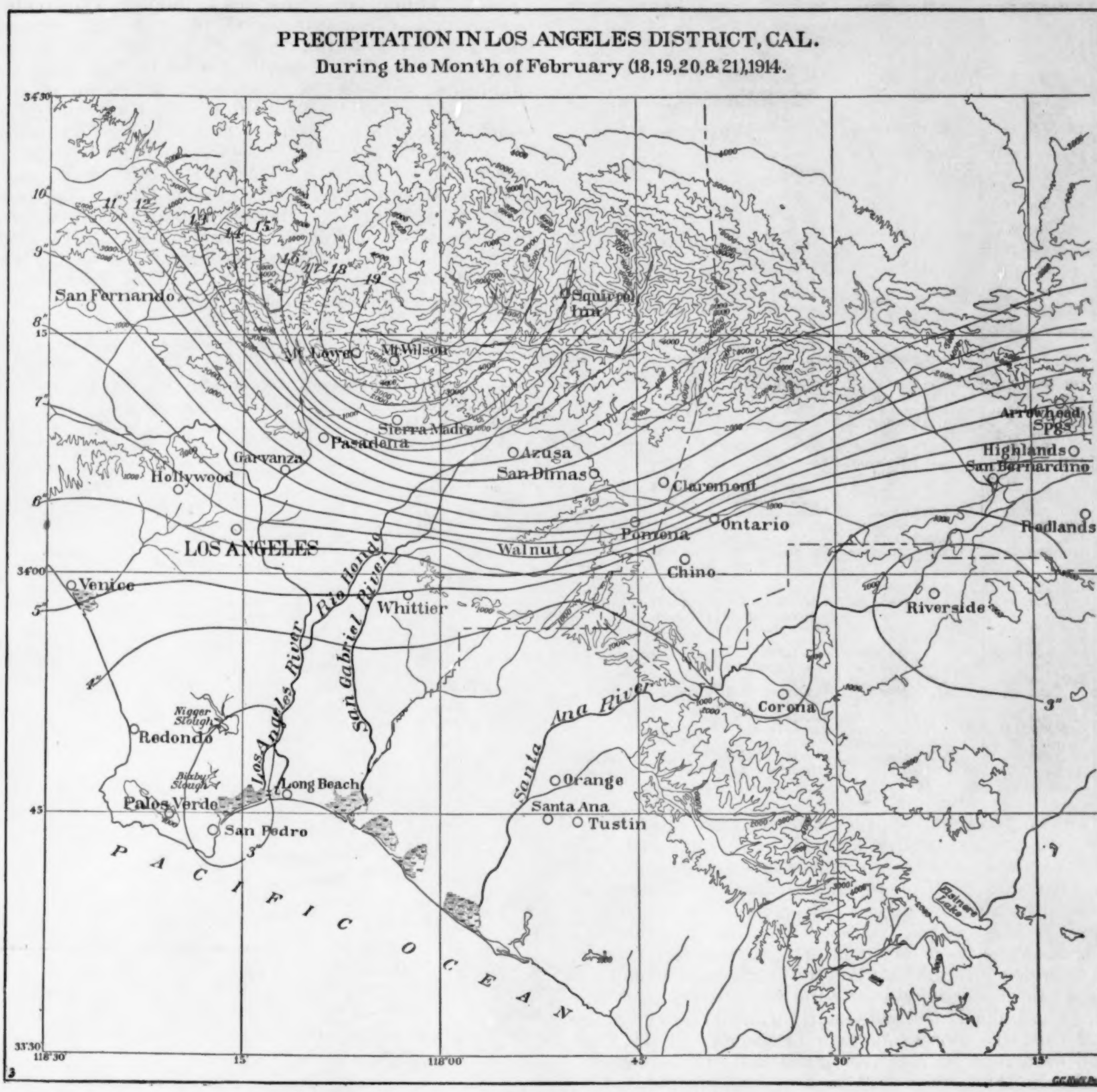

Fig. 3.—Isohyetal map of the Los Angeles district for February 18–21, 1914.

TABLE 2.—*Floods in vicinity of Los Angeles, Cal., for the 37 years 1878–1914.*

No.	Dates.	Precipitation, 24 hours.	Flood character.	Remarks.
		Inches.		
1	1878, Jan. 16....	1.16	Light.....	Bridges washed away.
2	Feb. 19....	1.33	Moderate..	Do.
3	1879, Dec. 20....	4.34	...do......	Mountain streams swollen. Bridges washed away. Railway travel suspended.
4	1880, Dec. 20....	2.26	...do......	Streets almost impassable.
5	1884, Feb. 17....	3.56	Heavy....	Severe flood. Great amount of damage. (Harbor silted.)
6	Mar. 9.....	2.67	...do......	Los Angeles River in flood. Houses washed away.
7	1886, Jan. 19....	3.77	...do......	Lower portion of city under water. Flood quite severe. Several lives lost.
8	1887, Feb. 16....	3.94	Moderate..	Severe flood, but not so bad as last year. Lower part of city flooded.
9	1888, Jan. 4.....	3.39	...do......	Several washouts in vicinity.
10	Dec. 23....	2.72	...do......	Many washouts. Streets flooded. Damage not commensurate with severity of storm.
11	1889, Mar. 17....	2.53	Light.....	Washouts. Streets in bad condition. River did not overflow.
12	Oct. 23....	3.62	Moderate..	Washouts on railroads. Unprecedented rainfall for this time of year. Streets flooded.
13	Dec. 12, 15.	4.30	Heavy....	Traffic paralyzed by washouts. Streets flooded.
14	Dec. 25....	3.82	...do......	The flood was scarcely less severe and disastrous than that of 1884. (Harbor silted.)
15	1890, Jan. 26....	4.17	...do......	Flood. Streets turned into rivers. Traffic suspended. (Harbor silted.)
16	1891, Feb. 23....	2.75	Moderate..	Many washouts. Bridges carried away. River high.
17	1893, Mar. 21....	2.82	...do......	Streets flooded.
18	1894, Dec. 21....	1.33	Light......	Do.
19	1895, Jan. 17–18.	1.73	...do......	Do.
20	1896, Dec. 28....	1.22	...do......	Do.
21	1897, Jan. 14–15.	1.57	...do......	Do.
22	Feb. 20....	2.02	...do......	Do.
23	1900, Nov. 21...	3.79	Moderate..	Flood.
24	1901, Feb. 6.....	2.55	Light.....	Streets flooded.
25	Oct. 27....	1.79	...do......	Streets flooded. Railroad traffic temporarily suspended.
26	1902, Nov. 11...	1.95	...do......	Streets flooded.
27	1903, Mar. 25....	3.35	Moderate..	Do.
28	1905, Feb. 4.....	2.25	Light.....	Do.
29	Mar. 13....	2.41	Moderate..	San Gabriel and Santa Ana Rivers very high. Streets flooded. Traffic interrupted.
30	1906, Jan. 19....	2.20	Light.....	Streets flooded, but no serious damage.
31	Mar. 26....	1.75	Moderate..	Los Angeles River higher than for many years. Streets inundated.
32	1907, Jan. 7–8...	1.64	Light.....	Streets flooded.
33	1908, Jan. 24....	1.76	...do......	Do.
34	1909, Jan. 21–22.	3.17	Moderate..	Streets flooded. Traffic interrupted.
35	Dec. 31....	1.99	...do......	Streets flooded.
36	1911, Jan. 28....	2.97	...do......	Do.
37	Mar. 9.....	1.99	Heavy....	Streets flooded. Traffic interrupted. (Harbor silted.)
38	1912, Mar. 9–12..	2.04	Light......	Streets flooded.
39	1913, Feb. 24....	5.12	Moderate..	Streets flooded. Traffic interrupted.
40	1914, Jan. 25....	2.60	...do......	Do.
41	Feb. 18....	4.26	Heavy....	Streets flooded. Traffic interrupted. Bridges washed away. (Harbor silted.)

Contributing causes shown by accumulated rainfall profiles.—Figure 5 (p. 390) is a profile of accumulated daily rainfall in which the record is made to begin October 2 and end with April 2. The horizontal values are in inches and hundredths and the vertical divisions in days and decades. A glance at this chart will show that in a majority of seasons the floods occur after the second heavy rain, provided the interval between the storms is not too long. If the rain is steady, allowing the water to soak into the thirsty soil, floods will not occur, no matter how great the total rainfall. For example, on December 31, 1878, no flood occurred although 3.58 inches fell in the 24 hours; as also in 1892, when 3.75 inches were precipitated on November 29; and again on February 1, 1897, when 2.13 inches were recorded. But without an exception, in these instances floods occurred during the next period of rainy weather. The profiles do not reveal any instance where floods occurred simultaneously with the first storm. They indicate that there are three important factors in the production of floods in the Los Angeles district: First, the interval elapsing between the last rain and the flood; second, the rapidity of the rainfall, and third, the total amount deposited.

During the past 15 years the local office of the Weather Bureau has maintained automatic rain gages which give very satisfactory records of the actual rate of fall in 1-minute and 5-minute periods. This record is shown in Table 3. It may be summarized as follows: The greatest amount in any 5-minute period was 0.36 inch, between 1 p. m. and 1:30 p. m., February 18, 1914; and during the same hour the 10-minute record of 0.66 inch was established, as was also the 15-minute record of 0.81 inch, and the greatest amount in 30 minutes, 1.12 inches. The greatest amount in one hour, 1.51 inches, fell on February 18, 1914; of this amount 1.16 inches occurred in 32 minutes. The rate of 2.50 inches in 24 hours was maintained for 20 hours and 27 minutes during this storm. The greatest amount in 24 hours was 5.12 inches, which fell on February 23–24, 1913. Excessive rainfall, as automatically registered on the day of the 1914 storm, is shown in detail by Table 4 and graphically by figure 6 (p. 391).

TABLE 3.—*Excessive precipitation at Los Angeles, Cal., for the 15 years, 1899–1914.*

Duration.	Amounts.	Dates.	Pacific time.
	Inches.		
5 min....	0.12	Jan. 2, 1899	7:38 p. m. to 7:43 p. m.
Do.....	.20	Feb. 2, 1905	(Early morning.)
Do.....	.15	Feb. 10, 1906	
Do.....	.22	Mar. 12, 1906	
Do.....	.18	Mar. 5, 1907	
Do.....	.14	Jan. 21, 1909	Between 3 and 4 p. m.
Do.....	.15	Mar. 4, 1912	10:08 a. m. to 10:13 a. m.
Do.....	.11	Mar. 6, 1912	6:28 a. m. to 6:33 a. m.
Do.....	.14	Mar. 12, 1912	11:44 a. m. to 11:49 a. m.
Do.....	.14	Jan. 15, 1913	
Do.....	.24	Nov. 12, 1913	
Do.....	.28	Jan. 18, 1914	Between 5 a. m. and 6 a. m.
Do.....	.36	Feb. 18, 1914	Between 1 p. m. and 1:30 p. m.
7 min....	0.51	Jan. 14, 1908	4:16 a. m. to 4:23 a. m.
Do.....	.23	Feb. 9, 1908	6:38 a. m. to 6:45 a. m.
10 min...	0.40	Nov. 12, 1913	
Do.....	.42	Jan. 18, 1914	
Do.....	.66	Feb. 18, 1914	
15 min...	0.44	Nov. 27, 1905	
Do.....	.48	Jan. 18, 1914	
Do.....	.49	Nov. 12, 1913	
Do.....	.81	Feb. 18, 1914	
20 min...	0.75	Nov. 17, 1900	Between 12:30 p. m. and 1 p. m.
30 min...	0.68	{Mar. 13, 1905 {Nov. 12, 1913	
Do.....	1.12	Feb. 18, 1914	
60 min...	1.51	Feb. 18, 1914	
24 hours..	5.12	{Feb. 23, 1913 {Feb. 24, 1913	
Do.....	4.26	Feb. 18, 1914	

Lessons from the flood.

Loss by heavy rain is not unknown in the Los Angeles district, the flood of 1914 being the third severe flood in local history, and the eighth known heavy flood. Records show that the floods of 1884 and 1889 were more serious than that of 1914. In fact, there appears to be no

question but that another series of heavy rains which characterized the floods in the spring of 1884 would make the last storm appear inconsequential. It should be remembered that when the great flood took place 30 years ago, Los Angeles was a town of probably less than 20,000 inhabitants. With its present population of approximately half a million, the run-off area has been greatly increased owing to the thousands of acres of roofs, paved streets, sidewalks, etc., while the absorption area has been correspondingly lessened from the same cause. The steady progress in building, especially during the last decade, has indirectly diminished the damage by floods because of the resultant considerable consumption of sand in the manufacture of concrete. This sand, dredged from the Los Angeles River, has proportionately deepened the channel of the river where it passes through the city.

It has been estimated that New York City's last snowstorm cost $2,500,000 for snow removal alone, and that the storms resulted in damage amounting to $5,000,000 at the lowest conservative estimate.[2] While the damage by one of the comparatively infrequent floods in Los Angeles does not much exceed the cost of removing snow from the streets of New York City during an ordinary snowstorm, and there can be no question but that the growth of the city and attendant rapidly increasing value of city and surrounding property will make the drainage and utilization of storm waters the most important questions now before the people of this city and surrounding region.

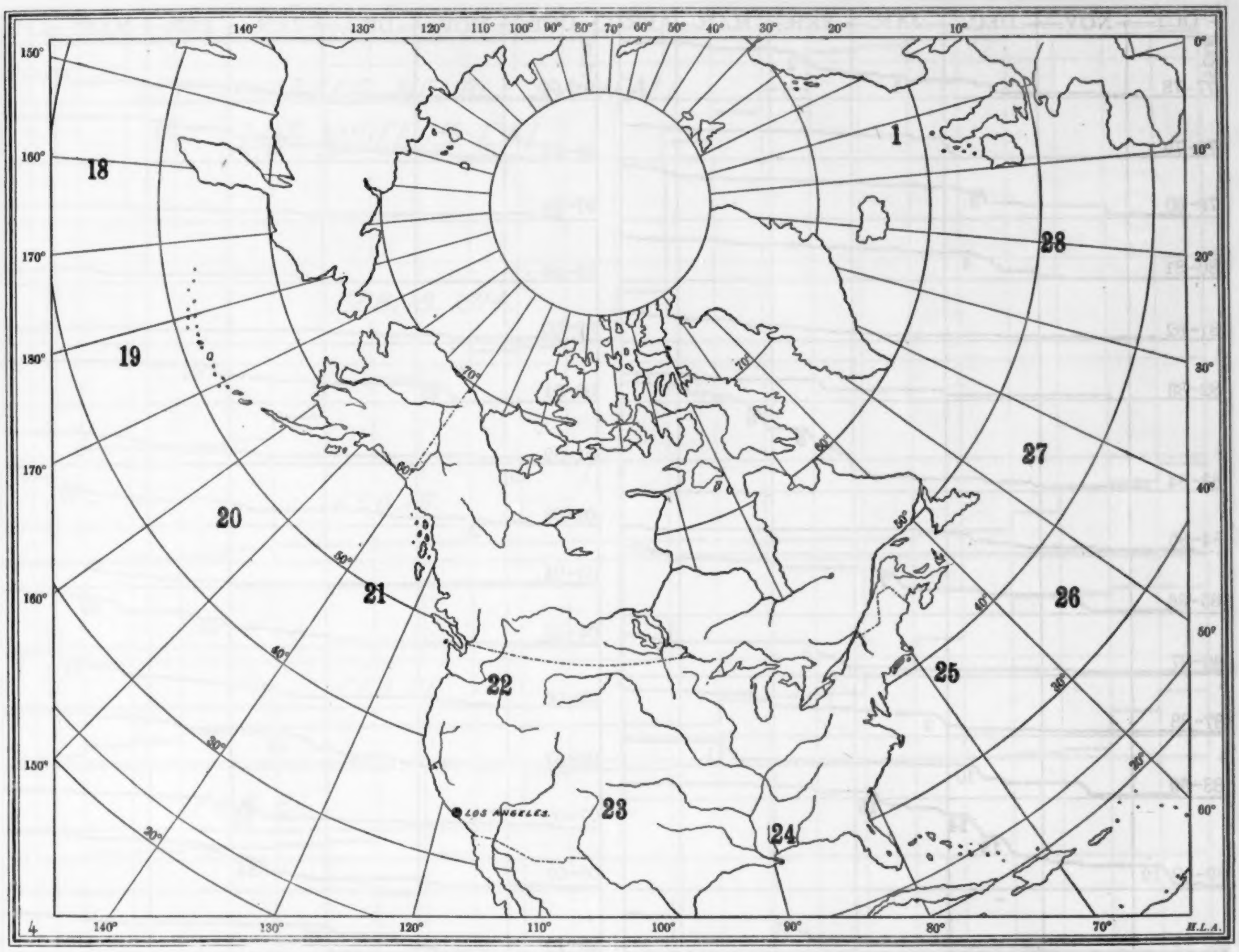

FIG. 4.—Progress of the storm of February 18, 1914. The dates Feb. 18–Mar. 1 indicate successive positions of the center.

[2] Eng'r'g record, Mar. 28, 1914, No. 13, 69:354.

TABLE 4.—*Excessive rainfall automatically registered Feb. 18, 1914, at the local office, United States Weather Bureau, Los Angeles, Cal.*

[1.16 inches in 32 minutes.]

ACCUMULATED DEPTHS, CONSECUTIVE PERIODS, MINUTES.

[Excessive rate began 12:27 p. m., ended 1:56 p. m., local time (Pacif. stand. T.).]

	Inches.
5 minutes	0.06
10 minutes	.11
15 minutes	.21
20 minutes	.29
25 minutes	.32
30 minutes	.35
35 minutes	.41
40 minutes	.45
45 minutes	.55
50 minutes	.63
60 minutes	.86
80 minutes	1.73
100 minutes	1.90

ARTIFICIAL DEEPENING OF THE ARKANSAS AT WICHITA, KANS.

By ALFRED J. HENRY, Professor of Meteorology, in charge of River and Flood Division.

The continuous removal of sand for building purposes from the bed of the Arkansas River immediately below the Douglas Avenue Bridge at Wichita has lowered the channel of the river at that point probably as much as 5 or 6 feet during the last 10 years.

The width of the river bed at Wichita is about 500 feet, but the channel at that point is not more than about 70 feet wide.

The observations of stages of water in the river by the Weather Bureau at Wichita were begun in the latter half of 1897, using a gage that had been constructed by the city of Wichita. The height of the zero of this gage was, so far as can now be determined, 1,284.7 feet above sea level. It was graduated from zero to 13 feet.

In 1905 the Weather Bureau constructed a new gage, the zero of which was placed at 1,284.7 feet above sea level. This gage was graduated from -0.5 to 12 feet. In 1907 it became necessary to extend the lower section of the gage from -0.5 to -3.0 feet. In 1909 the Weather Bureau erected a second new gage on the Douglas Avenue Bridge. This gage was at first graduated from -3.0 to 12 feet, but later, by reason of the lowering of

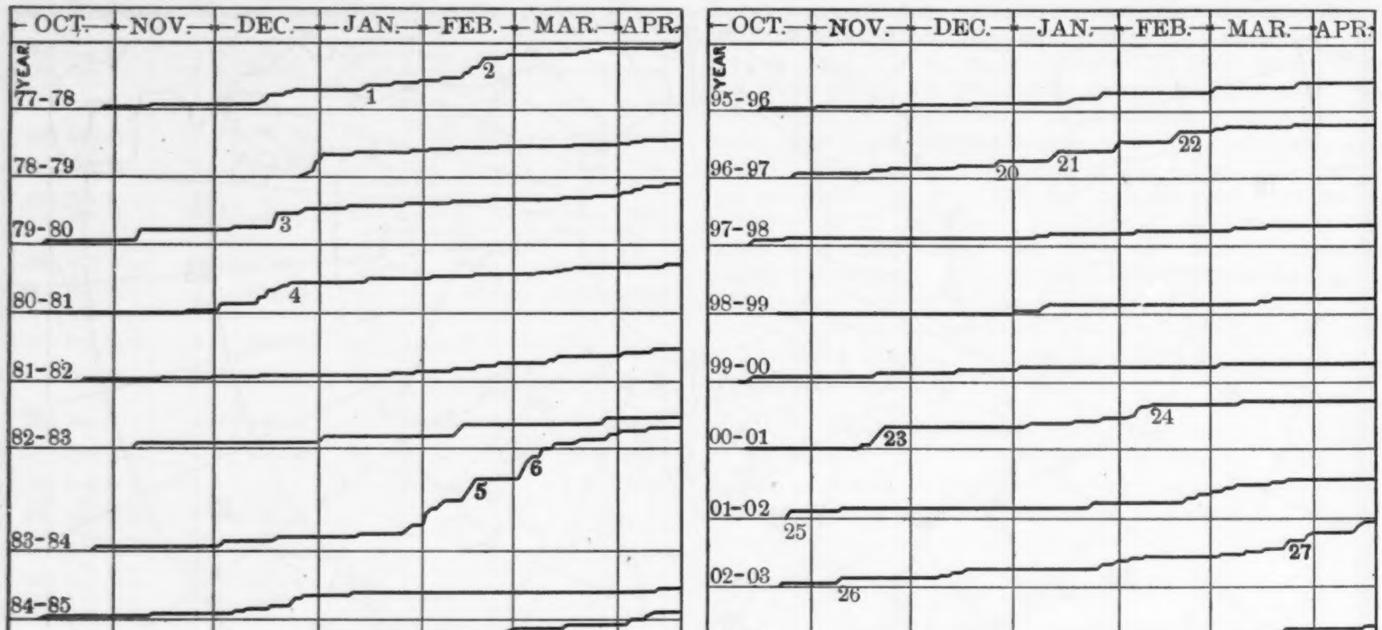

FIG. 5.—Profiles of accumulated precipitation at Los Angeles, Cal., for each of the 37 years, 1877-78 to 1913-14.

the channel, it was extended to −6.5 feet, at which point it remains. Thus the graduation of the gage has been extended from zero in 1897 to 6½ feet below zero in 1911. There has been no change in the zero of this gage.

In order to determine the approximate amount of lowering, a study of the gage relations between Wichita and Hutchinson, Kans., has been made. The last-named point is 43 miles up river from Wichita. Daily gage readings at Hutchinson were maintained by the United States Geological Survey from 1896 to 1903. During six years of that time corresponding readings were made at Wichita. Beginning in 1909, the Weather Bureau, using the gage of the United States Geological Survey, continued the series of daily readings at Hutchinson through the months of April to August of each year until 1913, when the station was finally closed. Thus there is available two series of comparative readings, the first extending from 1898 to 1903 and the last from 1909 to 1912.

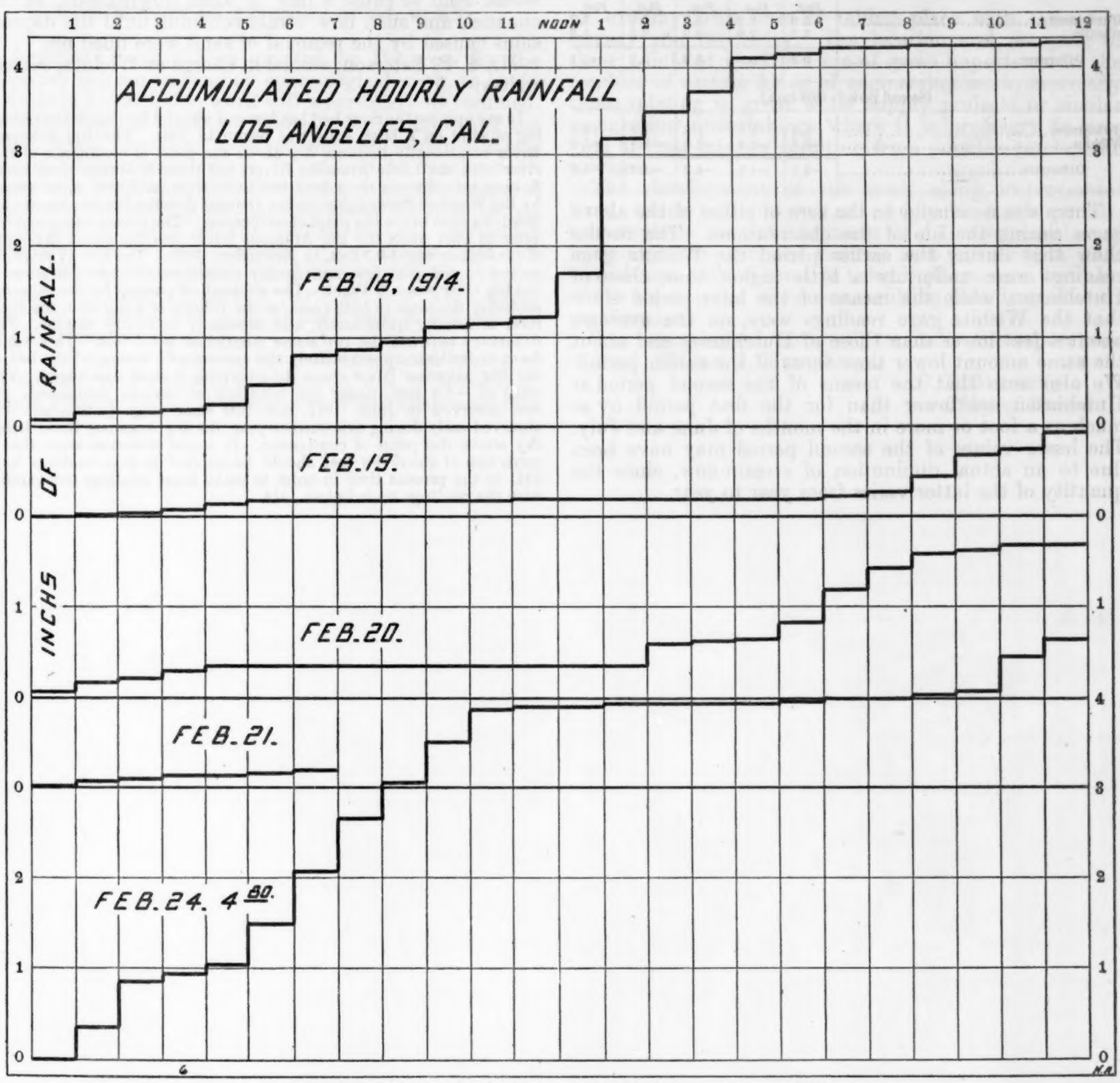

FIG. 6.—Accumulated hourly rainfalls, Los Angeles, Cal., February 18-21 and 24, 1914.

Inasmuch as the zeros of both gages were set approximately at the bed of the river, the monthly mean values should enable us to determine whether or not the gage relations which existed in the early period continued throughout the second period.

The comparative means are given below.

TABLE 1.—*Monthly mean river gage readings, Hutchinson and Wichita, Kans.*

[First period: 1898-1903.]

Station.	April.	May.	June.	July.	August.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Hutchinson	2.0	2.2	3.0	2.0	1.7
Wichita	2.3	2.8	3.9	2.2	1.9
Difference	0.3	0.6	0.9	0.2	0.2
[Second period: 1909-1912.]					
Hutchinson	1.4	1.6	1.6	1.0	1.4
Wichita	−2.7	−2.4	−2.6	−3.4	−3.2
Difference	−4.1	−4.0	−4.2	−4.4	−4.6

There was no change in the zero of either of the above gages during the life of the observations. The results show that during the earlier period the Wichita gage readings were uniformly a little higher than those of Hutchinson, while the means of the later period show that the Wichita gage readings were, on the average, about 4 feet lower than those of Hutchinson and about the same amount lower than those of the earlier period. We also note that the means of the second period at Hutchinson are lower than for the first period by as much as a foot or more in the months of June and July. The lesser values of the second period may have been due to an actual diminution of stream-flow, since the quantity of the latter varies from year to year.

We assume that the stream-flow at Hutchinson and Wichita is practically identical, since no diversion of water is made between the two points. The character of the bottom is the same at both points, viz, sandy and shifting. So far as known, no considerable quantity of sand was removed from the river channel at Hutchinson.

The removal of sand from the river bed at Wichita would tend to cause a flow of sand downstream, in the channel, and such flow would continue until the depressions caused by the removal of sand were filled up.

Mr. S. P. Peterson, official in charge at Wichita, Kans., writes:

In my opinion the river bed has lowered about 6 feet since the pumping of sand on a large scale was begun in 1904. The Big Arkansas River occasionally becomes dry above the point of confluence of this river with the Little Arkansas River, but there is always some water flowing into the big river from the little river, and this water passes by the Weather Bureau gage on the Douglas Avenue Bridge, about one-third of a mile below the point of confluence. The lowest stage recorded prior to 1904 when the Big Arkansas River was dry about the point of confluence was +0.7 foot, in November, 1897. The lowest stage observed in the past few years under similar conditions of dryness of the big river was −5.4 feet. The stream-flow passing by the gage was probably the same in both cases, as the volume of water from the little river is usually quite small, and especially so in dry seasons. The difference between the two stages mentioned is 6.1 feet. This would seem to indicate approximately the amount of lowering of the bed of the Big Arkansas River since the pumping of sand was begun. The stage of −5.4 feet, under the condition of dryness mentioned, was first observed in June, 1911, and this same stage (estimated) was observed early during this current year, the Big Arkansas River being dry above the point of confluence. It would therefore seem that a correction of about +6 feet should be applied to gage readings from 1911 to the present time in order to make these readings comparable with the readings made before 1914.

ANNOUNCEMENT.

RESUMPTION OF SEISMOLOGICAL WORK.

Authority having been granted by Congress for the Weather Bureau to conduct seismological work, to begin with July 1, 1914, this work will accordingly be resumed.

As but limited funds are available for inaugurating the work, it will consist at the beginning of a systematic collection of noninstrumental reports, to be rendered on post cards or other appropriate form, giving the essential features of such slight earthquakes as are likely to be felt in almost any part of the United States. Particular attention will be paid, however, to the Pacific coast and Rocky Mountain regions; the Mississippi Valley in the vicinity of Missouri; certain parts of New York State and New England, and possibly the region in the vicinity of Charleston, S. C.

It is believed that by the collection and study of numerous reports of this character it will be possible to locate sections of the United States where seismic motion on existing fault lines is taking place with some frequency and regularity. The location and mapping of these points of weakness are of great importance in the conduct of certain kinds of engineering work, especially those relating to great water supply projects or similar engineering undertakings where it is necessary to provide against injuries resulting from possible earthquake motions.

The development of the work along instrumental lines, which will proceed as rapidly as funds permit, contemplates the establishment of a limited number of instrumentally equipped stations that will serve to yield records not only of sensible seismic phenomena but also of the great unfelt vibrations resulting from large distant earthquakes.

The seismological work will be under the supervision of Prof. William J. Humphreys.

C. F. MARVIN,
Chief of Bureau.

SECTION V.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

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RECENT PAPERS BEARING ON METEOROLOGY.

C. FITZHUGH TALMAN, Professor in charge of Library.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

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Elsner, G[eorg] v. Zur Frage des Temperaturunterschiedes zwischen der Luft auf Berggipfeln und der freien Atmosphäre in gleicher Höhe. p. 286–287.
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NOTES FROM THE WEATHER BUREAU LIBRARY.

By C. FITZHUGH TALMAN, Professor in charge of Library.

METEOROLOGY IN THE SCIENTIFIC JOURNALS.

What scientific journals should be read by the meteorologist in order that he may maintain at least a paper-knife aquaintance with the whole multifarious progress of his science? If he be a specialist in certain branches of meteorology, in which journals will he find the most and the best literature pertaining to his specialty? These questions become more and more important as the number of scientific periodicals increases, since there is, as yet, no corresponding increase in the extent to which the literature of each science is segregated, while such nominal segregation as exists is complicated by the overlapping of the sciences, so that meteorology, for example, finds itself dismembered in response to the demands of the physicist, the geographer, the astrophysicist, the geologist, the biologist, the aeronaut, and many others. Bibliographies are of limited utility in disentangling this complication. By the time a scientific memoir is pigeonholed and ticketed in the bibliographies it has lost something of its pristine charm and interest; hence these compilations, though indispensable for many purposes, do not fully meet the requirements of the student whose ambition it is to keep fully abreast of the times and even a little ahead of the times.

Of the journals devoted wholly to meteorology little need be said. They are so few that the meteorologist can easily find time to read all of them, and he naturally does so, except when the languages in which they are published prove an insuperable barrier. Fortunately the reader who knows English, French, German, and Italian need not miss much meteorological literature of world-wide interest. Doubtless he sometimes feels rather tantalized at the sight of the Meteorologicheskii Viestnik (in Russian), Az Időjárás (in Hungarian), or the Journal of the Meteorological Society of Japan (which is mostly in Japanese, though occasional papers are published in English, German, and—Esperanto!); but it is safe to say that there is little of permanent interest in the contents of these exotic publications—except, perhaps, some papers dealing with local climatology—which does not find its way, in abstract or translation, into the journals published in more familiar tongues. Hemel en Dampkring (the leading Dutch journal of astronomy and meteorology) can be negotiated with tolerable facility by the reader who has a good knowledge of German, and a Dutch dictionary at hand for occasional reference.

The Meteorologische Zeitschrift must be named first among the purely meteorological journals published in languages which the majority of meteorologists can read. It is the arena in which the most advanced and vital questions are fought out by acknowledged leaders in the several branches of the science to which it is devoted. The Zeitschrift, the Quarterly Journal of the Royal Meteorological Society, and the Monthly Weather Review, with perhaps, the Beiträge zur Physik der freien Atmosphäre, are the indispensable journals to the meteorologist of English speech; but this statement is by no means intended to disparage the great importance of such publications as the Annuaire de la Société Météorologique de France (published monthly, in spite of its name), Das Wetter, the Journal of the Scottish Meteorological Society, Symons's Meteorological Magazine, the Memoirs of the Indian Meteorological Department, the Bolletino of the Società Meteorologica Italiana, the Annalen der Hydrographie und maritimen Meteorologie, and Ciel et Terre (which last, however, is now rather more astronomical than meteorological). Certain annual publications need to be enumerated here, notably the annual reports of the Bureau Central Météorologique de France, the Royal Prussian Meteorological Institute, the Uffizio Centrale di Meteorologia (Rome), and the Lindenberg Observatory, all of which, besides administrative and statistical matters, contain numerous memoirs of the highest interest. The Annuaire Météorologique of the Royal Observatory of Belgium is a somewhat analogous publication, while there are many yearbooks of other meteorological services and observatories which contain occasional memoirs dealing with problems in general meteorology.

The purpose of the present note is not, however, to discuss the ostensibly meteorological journals, but to point out publications of a more general character, or devoted to particular subjects other than meteorology, which nevertheless the meteorologist ought to see regularly on account of the large amount of literature they contain relating directly to his science. The task of selection is not easy. A long list would defeat its purpose, since the average meteorologist has not time to read all the publications that might, with more or less propriety, be enumerated here, nor, in most cases, would he have access to all of them. On the other hand, the writer feels reluctant to omit any of the journals, some two hundred in number, which, with great profit to himself, he searches regularly for meteorological papers to be catalogued in the library, and listed among "Recent Papers" in the MONTHLY WEATHER REVIEW. The editors of the journals not mentioned below will, of course, understand that the principal criterion governing our selection is the amount

of purely meteorological material ordinarily found in the various publications considered in making up this list, so that the omission of a journal is not a reflection upon its general merit or scientific standing. In fact, the writer proposes merely to jot down a list of the publications that come first to his mind as being of special interest to meteorological readers, without making a critical examination of the files of all the journals at hand in order to verify his impressions.

Two weekly publications which every meteorologist—and, in fact, every man of science—reads as a matter of course are Nature (London) and the Comptes rendus of the French Academy of Sciences. Nature is "the scientific man's newspaper," and a "newspaper" according to English canons of dignity and scholarship. In the Comptes rendus the various sciences are conveniently segregated, so that generally the meteorologist finds all that he wants on the last three or four pages of each number. This publication is, of course, totally different in purpose and scope from Nature, and we mention them together merely because they are both weeklies and both indispensable. The American weekly Science publishes, intermittently, a department of meteorological notes and abstracts, but otherwise devotes much less attention to meteorology than does its English contemporary. Among the more popular weeklies, the Scientific American, Prometheus, La Nature, and Cosmos contain meteorological articles or news notes in every number.

Coming, now, to the journals of general science issued monthly or at other intervals longer than a week, certain of these deserve special mention as the recognized channels for the publication of the most important meteorological memoirs written in the countries where they appear. Thus the Sitzungsberichte of the Vienna Academy of Sciences publishes the most substantial contributions of Austrian meteorologists which are too long to appear in the Meteorologische Zeitschrift, and a somewhat analogous service is performed in Russia by the Memoirs of the Imperial Academy of Sciences, and in Scotland by the Transactions of the Royal Society of Edinburgh. Of journals which are not so consciously enlisted in the service of meteorology, but in which this science is nevertheless well represented, may be mentioned the Proceedings and Philosophical Transactions of the Royal Society of London, the Philosophical Magazine, the American Journal of Science, the Journal of the Franklin Institute, the Proceedings of the American Academy, the Proceedings of the American Philosophical Society, the Archives des sciences, the Atti of the two "Lincei" academies in Rome, the South African Journal of Science, and, among more popular publications, Knowledge, Himmel und Erde, Das Weltall, and the Popular Science Monthly.

Among geographical journals: Petermanns Mitteilungen, Geographical Journal, Geographische Zeitschrift, Zeitschrift der Gesellschaft für Erdkunde zu Berlin, Bulletin of the American Geographical Society, Scottish Geographical Magazine, Annales de géographie, la Géographie, Bollettino della Reale Società geografica italiana, and, last but not least, Mitteilungen aus den deutschen Schutzgebieten, with its splendid contributions to the climatography of hitherto little-known parts of the world.

Among physical journals: Physikalische Zeitschrift, Annalen der Physik, Journal de Physique, Annales de physique, Physical Review, and Proceedings of the Tokyo Mathematico-physical society; together with such electrical journals as Elektrotechnische Zeitschrift, Electrician, Electrical World, Jahrbuch der Radioaktivität, and Radium.

Among astronomical journals: L'Astronomie, the Observatory, Annals of Harvard College Observatory (which publishes the memoirs from Blue Hill), and the Astrophysical Journal.

Of aeronautical journals the name is legion, and all of them are necessarily more or less concerned with the air and the science thereof. Perhaps Technique aéronautique and Deutsche Luftfahrer Zeitschrift are those which the meteorologist can least well afford to overlook.

In the miscellaneous class all of the following must certainly be included: Beiträge zur Geophysik, Terrestrial Magnetism and Atmospheric Electricity, Zeitschrift für Gletscherkunde, Zeitschrift für Gewässerkunde, Zeitschrift für Balneologie, Engineering News, Proceedings of the American Society of Civil Engineers, Aus dem Archiv der Deutschen Seewarte, and Zeitschrift für Instrumentenkunde.

Last come various abstracting journals, in which the overworked meteorologist may find tabloid versions of papers which he has not time to peruse more satisfactorily: Science Abstracts, Journal de physique, Fortschritte der Physik (the annual "kosmische Physik" volume), Beiblätter zu den Annalen der Physik, Experiment Station Record, and Bulletin of Agricultural Intelligence and Plant Diseases (the last two containing, especially, abstracts of papers on agricultural meteorology).

SECTION VI.—WEATHER AND DATA FOR THE MONTH.

EXCESSIVE PRECIPITATION AT OKLAHOMA, OKLA.

In the Meteorologische Zeitschrift for April, 1914, Prof Julius v. Hann draws attention to what he believed to be an unusually heavy rainfall of brief duration at Oklahoma, Okla., between 3:35 a. m. and 6:10 a. m., July 1, 1913.[1] Unfortunately the monthly table of accumulated excessive precipitation was misinterpreted in this case by Prof. Hann.

When this table, now called Table II, published monthly in this REVIEW for many years past, was devised it was found impracticable to make it sufficiently wide to accommodate on one line the record of accumulated falls that continued at an excessive rate for several hours. It was decided that in the latter case the record should be broken at the end of each 50 minutes, the accumulating amounts being recorded on successive lines until the excessive rate ended.

In the light of this explanation of the table it is clear that the entry for Oklahoma, Okla., under July 1, 1913, in the second line, 5-minute column (1.26 inches), represents the accumulated fall for 55 minutes; and that in the last line for Oklahoma, the entry in the 5-minute column (4.19 inches) represents the accumulated or total fall for 155 minutes during which the falls had been at an excessive rate as measured by the scale of excessive rates given under the heading "Description of Tables and Charts" (below p. 401). The fall for the last 5-minutes period was only 0.13 inch (3.3 mm.).

The above statement is published here because the erroneous interpretation referred to above is being widely published and attributed to this REVIEW, by both technical and popular European journals. Journals that have printed this error are requested to give equal prominence to this correction.—[C. A. jr.]

THE WEATHER OF THE MONTH.

By P. C. DAY, Climatologist and Chief of Division.

Pressure.—The distribution of the mean atmospheric pressure over the United States and Canada, and the prevailing directions of the winds, are graphically shown on Chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

The mean barometric pressure for the month as a whole was above the normal over the entire country, save in New England, the interior of Virginia and North Carolina, and locally in the middle Missouri Valley, where the means were slightly less than normal. The more marked plus departures appeared in the middle and west Gulf States, extending into eastern New Mexico, and in the upper Lake region and upper Mississippi Valley. However, as a rule the departures from the normal were not large, the means in most districts being near the normal values.

[1] See Monthly Weather Review, Washington, July, 1913, 41 : 1128.

During the first few days of the month a moderate high pressure area occupied the central and eastern districts, which passed to sea about the 3d, and was followed by a trough of low pressure, extending on the morning of the 4th from the Lake region westward to the northern mountain districts. By the following day a high pressure area of considerable magnitude overspread the Hudson Bay district and slowly moved southward during the next few days to the southeastern States.

On the 8th–10th a moderate depression moved eastward over the northern border States and Canadian Provinces, after which no barometric changes of consequence occurred until about the middle of the month, when a rather extensive area of high pressure advanced from the Canadian Northwest, overspread the central and northern districts during the following few days, and passed to sea about the 18th. From the 22d to the 25th relatively high pressure obtained over the southern States east of the Rocky Mountains, and from the last named date to the close of the month a disturbance of considerable energy moved across the central and northern districts from the Pacific Ocean to the Canadian Maritime Provinces, with considerable diminution in intensity with approach to the ocean.

The distribution of the highs and lows for the month was favorable for the occurrence of southerly winds as prevailing direction over most districts east of the Rocky Mountains, while the prevailing directions to the westward were variable.

Temperature.—The month opened with moderately warm weather over all parts of the country, and during the first few days a warm area advanced slowly eastward from the Canadian Northwest, reaching the great valleys by the 4th. At the same time cool weather set in over the far West and overspread the mountain districts during the next few days, with temperatures as low as or lower than had been recorded for many years at the same period, and with local snows and frosts at exposed points. About this time much cooler weather obtained over the northern districts from the upper Mississippi Valley eastward, but to the southward temperatures continued quite high.

About the 8th high pressure over the northeast and a moderate depression on the Middle Atlantic coast resulted in a marked fall of temperature in New England and the Middle Atlantic States. However, temperatures continued high over interior districts, but were moderate and below normal from the Rocky Mountain region westward. About the 11th the cool weather in the northeast gave way to much higher temperatures, while warm weather continued in central and southern districts, with readings as high as or higher than ever before recorded for the period of the year at many points on the 10th or 11th. By the middle of the month temperatures were everywhere moderate, except in the south, where they continued high, but during the next few days the warm weather there was displaced by more moderate temperatures, and about the 20th the weather was unusually cool for the season in the Lake region.

About the 22d unusually cold weather obtained in portions of the mountain districts, expecially in Wyoming and adjoining States, where heavy local frosts occurred. This cold area did not, however, advance eastward to any marked extent and in a day or two it had largely dissipated, but in the meantime there was a general warming up over eastern districts and temperatures had again become high in the south. During the last few days of the month temperatures were low for the season over northern districts from New England westward to the Rocky Mountains, but high temperatures continued in the south and the weather had become warmer in the far West.

The mean temperature for the month was above the normal over all sections from the Rocky Mountains eastward, save along the northern border and in New England, where minus departures occurred. The plus departures ranged from 3° to 6° in all central and southern districts east of the Plains States. To westward of the Rocky Mountains the month was everywhere cooler than the average, except in the extreme southwest where the mean temperature was slightly above the normal, the more marked minus departures occurring in the central and northern Plateau region and along the northern coast of California.

The extremes of temperature during the month were frequently quite marked, especially the maximum readings in central and southern districts east of the Plains States about the 10th and 12th, and again about the 24th to 27th, when they were frequently above 100° and at numerous points equaled or exceeded any previous record for June. Minimum temperatures were quite low at points in the Lake region on the 17th and the 20th, and along the California coast during the last decade of the month.

Precipitation.—Unsettled, showery weather prevailed over the more western districts during much of the first week of the month, and from the 4th to the 9th precipitation was quite general over all northern districts from the Rocky Mountains eastward to New England. From the 8th to the 15th precipitation was generous over the Missouri and upper Mississippi valleys and portions of the middle and northern Rocky Mountain region and locally in the lower Mississippi Valley, the east Gulf and South Atlantic States, with some heavy falls in portions of the upper Mississippi Valley and northern Plains States. From the 15th to the 20th the rainfall was mostly of a local character, but large areas of the country received generous amounts, especially the Lake region, central and western Texas, portions of the Mountain districts and locally in the southeastern States, but considerable areas in the middle Mississippi and Ohio valleys and Middle Atlantic States received little or no precipitation.

During the last decade of the month the rainfall was above the normal and in some cases excessive over portions of the Middle Atlantic States and all northern districts from the Lake region westward to the Pacific coast, the falls in portions of North Dakota, Minnesota, and Wisconsin being especially heavy; but over the central and southern sections little or no rain occurred during the decade.

For the month as a whole the precipitation was heavy, ranging from 6 to 8 inches, in the upper Mississippi Valley and the northern Plains States, and was above the normal in all central and northern districts from the Lake region westward to the Pacific, save in Missouri and portions of adjoining States, Wyoming, and the far Northwest. In all other districts the amounts were quite generally below the normal, with some marked deficiencies in the central and eastern districts, and to the southward. Little rain occurred during the month in the middle Mississippi Valley and southwestward over Oklahoma and much of Texas, and the total falls were also light in portions of the Middle Atlantic States.

For the season, March 1 to the end of June, the precipitation was decidedly below the normal over all central and southern districts east of the Rocky Mountains, save in Texas, the minus departures ranging from 4 to 8 inches, and less than the average amount was likewise received in the Pacific Coast States and over much of the northern mountain region. The total for the season was above the normal in much of the Lake region, the northern Plains States, the central and southern mountain districts, and in Texas.

GENERAL SUMMARY.

The more noteworthy features of the month's weather were the heavy rainfall in the northern districts from the Lake region westward to and including the northern mountain States, and the scanty amounts and excessive temperatures over the central and southern sections east of the mountains. The weather was favorable for maturing winter wheat and for harvesting where cutting had begun, as well as for rapid growth in the spring wheat belt, but somewhat too much moisture was received in portions of the latter region. In most western and northern districts the month's weather favored corn, hay, and oat growth, but in the Ohio Valley and to the southward the hot, dry weather was unfavorable, and oats and hay were cut short in many sections and the growth of corn was retarded and the crop much damaged in the more southern districts.

In the cotton belt the month was exceeding dry and hot, despite which early planted cotton made good growth, but the trucking interests of the South suffered severely from lack of moisture.

The precipitation during the month was sufficient to keep the ranges of the West generally in good condition, but at the close more moisture was needed in many central and southern sections.

Over the Pacific Coast States the weather of the month was generally favorable, but some damage to wheat occurred by frost near the close in the northern highlands.

Maximum wind velocities, June, 1914.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
		Mi./hr.				*Mi./hr.*	
Bismarck, N. Dak..	25	53	e.	Nashville, Tenn....	12	52	nw.
Charleston, S. C....	9	58	ne.	Do..............	15	65	nw.
Cheyenne, Wyo....	20	50	w.	Do..............	25	62	sw.
Do..............	26	58	w.	New York, N. Y....	16	55	nw.
Columbus, Ohio....	4	55	nw.	Do..............	20	56	nw.
Do..............	26	54	sw.	Parkersburg, W.Va.	22	57	nw.
Devils Lake, N.Dak.	6	50	sw.	Pierre, S. Dak......	26	56	w.
Duluth, Minn......	4	54	ne.	Do..............	27	50	nw.
Do..............	27	62	ne.	Pittsburgh, Pa......	27	53	nw.
El Paso, Tex.......	1	58	se.	Point Reyes Light, Cal..............	2	52	nw.
Grand Junction, Colo..............	6	55	sw.	Do..............	3	73	nw.
Huron, S. Dak......	3	58	nw.	Do..............	4	94	nw.
Lincoln, Nebr......	14	52	nw.	Do..............	5	67	nw.
Minneapolis, Minn..	18	56	n.	Do..............	11	50	nw.
Do..............	23	67	nw.	Do..............	20	76	nw.
Modena, Utah......	5	50	n.	Do..............	21	60	nw.
Do..............	24	52	sw.	Do..............	22	61	nw.
Do..............	25	51	sw.	Providence, R. I....	16	52	nw.
Mount Tamalpais, Cal..............	4	74	nw.	Rapid City, S. Dak.	25	50	sw.
Do..............	5	67	nw.	St. Paul, Minn.....	10	50	se.
Do..............	6	68	nw.	Do..............	23	56	nw.
Do..............	10	52	nw.	Sioux City, Iowa...	13	54	s.
Do..............	18	50	sw.	Do..............	23	67	s.
Do..............	23	53	nw.	Do..............	27	53	w.
Mount Weather, Va.	27	58	w.	Valentine, Nebr....	12	56	e.
Do..............	29	56	nw.	Wichita, Kans......	5	50	nw.
Do..............	30	56	nw.	Williston, N. Dak..	3	50	n.

Average accumulated departures for June, 1914.

Districts.	Temperature. General mean for the current month.	Temperature. Departure for the current month.	Temperature. Accumulated departure since Jan. 1.	Precipitation. General mean for the current month.	Precipitation. Departure for the current month.	Precipitation. Accumulated departure since Jan. 1.	Cloudiness. General mean for the current month.	Cloudiness. Departure from the normal.	Relative humidity. General mean for the current month.	Relative humidity. Departure from the normal.
	° F.	° F.	° F.	Ins.	Ins.	Ins.			P. ct.	P. ct.
New England	62.1	−1.0	− 6.9	2.21	−0.90	−2.00	5.3	+0.1	70	− 9
Middle Atlantic	70.9	+0.8	− 1.1	2.84	−0.90	−2.70	5.1	+0.1	63	−10
South Atlantic	79.3	+3.3	+ 2.9	3.09	−1.80	−7.90	5.0	0.0	74	− 4
Florida Peninsula	81.6	+1.1	− 3.1	2.78	−4.00	−6.10	4.6	−0.6	75	− 5
East Gulf	82.8	+4.7	+ 2.0	2.85	−1.70	−6.10	4.0	−0.7	70	− 5
West Gulf	82.4	+3.4	+ 2.2	0.73	−3.00	−5.40	3.4	−0.9	69	− 7
Ohio Valley and Tennessee	76.5	+3.3	+ 0.8	2.85	−1.40	−6.40	4.7	−0.3	63	− 7
Lower Lakes	66.1	−0.9	− 6.2	2.51	−1.10	+0.40	4.8	−0.1	67	− 4
Upper Lakes	62.5	−0.1	+ 1.3	4.75	+1.40	+0.90	5.3	−0.2	71	− 2
North Dakota	63.2	−0.5	+10.6	7.84	+4.20	+2.90	8.5	+0.4	74	+ 6

Average accumulated departures for June, 1914—Continued.

Districts.	Temperature. General mean for the current month.	Temperature. Departure for the current month.	Temperature. Accumulated departure since Jan. 1.	Precipitation. General mean for the current month.	Precipitation. Departure for the current month.	Precipitation. Accumulated departure since Jan. 1.	Cloudiness. General mean for the current month.	Cloudiness. Departure from the normal.	Relative humidity. General mean for the current month.	Relative humidity. Departure from the normal.
	° F.	° F.	° F.	Ins.	Ins.	Ins.			P. ct.	P. ct.
Upper Mississippi Valley	73.6	+2.7	+ 9.5	4.56	+0.20	−3.30	5.1	+0.1	66	− 4
Missouri Valley	74.6	+3.7	+14.3	5.86	+1.50	−0.80	4.4	−0.5	68	+ 1
Northern slope	61.9	−0.2	+13.8	2.70	+0.40	−1.10	5.2	+0.4	62	+ 5
Middle slope	75.9	+4.0	+13.5	2.33	−0.80	−2.00	3.7	−0.3	59	− 1
Southern slope	78.0	+0.8	+ 6.1	1.84	−1.00	+0.40	3.8	0.0	62	− 2
Southern Plateau	76.7	−0.9	+ 3.8	0.65	+0.30	+0.20	2.8	+0.8	40	+13
Middle Plateau	63.3	−1.9	+ 9.1	1.43	+0.90	+0.80	3.8	+0.5	46	+ 9
Northern Plateau	61.7	−3.2	+14.5	1.44	+0.30	−0.90	5.3	+0.7	54	+ 3
North Pacific	56.8	−0.8	+13.7	1.94	−0.10	+0.10	5.7	−0.4	77	+ 1
Middle Pacific	60.5	−2.1	+ 8.0	0.79	+0.40	−0.40	3.9	+0.6	66	+ 4
South Pacific	65.6	−0.5	+14.3	0.14	0.00	+3.80	3.4	+0.1	68	+ 2

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Summary of temperature and precipitation, by sections, June, 1914.

Section.	Temperature—in degrees Fahrenheit. Section average.	Departure from the normal.	Monthly extremes. Station.	Highest.	Date.	Station.	Lowest.	Date.	Precipitation—in inches and hundredths. Section average.	Departure from the normal.	Greatest monthly. Station.	Amount.	Least monthly. Station.	Amount.
Alabama	83.1	+5.1	Maple Grove	109	26	Lock No. 4	51	11	2.66	−1.80	Eufaula	8.64	Cochrane	0.10
Arizona	76.1	+1.0	Sentinel	119	27	2 stations	28	3†	0.66	+0.36	Paradise	2.38	3 stations	0.00
Arkansas	82.3	+6.1	Wiggs	109	28	Dutton	52	28	1.00	−3.13	Huttig	3.77	Alicia	0.00
California	66.4	−2.6	Greenland Ranch	124	29	Summit	20	5	0.85	+0.54	Magalia	5.57	32 stations	0.00
Colorado	62.4	+1.1	Holly	102	13†	Aspen	20	15	1.80	+0.41	Sedgwick	6.22	Fraser	0.40
Florida	81.9	+2.4	Middleburg	107	24	Griffin	58	6	4.03	−2.58	Archer	9.19	Sand Key	0.14
Georgia	82.2	+4.4	Waynesboro	109	25	Gainesville	51	19	3.51	−1.24	Valdosta	8.75	Canton	0.78
Hawaii [for May]	71.1	......	Waialua	91	24	Waimea	52	6	12.40	......	Waiakamoi	60.68	Waianae	0.68
Idaho	58.8	−1.7	Glenns Ferry	106	18	Pierson	14	6	2.13	+1.03	Castle Creek	4.97	Arrowrock	0.32
Illinois	75.5	+3.8	7 stations	105	24†	Sycamore	37	16†	2.60	−1.10	Yorkville	7.82	East St. Louis	0.09
Indiana	75.0	+3.7	2 stations	106	10†	Auburn	38	20	2.38	−1.57	Marengo	5.74	Elliston	0.26
Iowa	72.2	+3.1	.....do	101	9†	2 stations	40	2†	5.57	+1.19	Osage	13.24	Bonaparte	1.17
Kansas	78.2	+5.4	Santa Fe	109	28	Irene	40	9	4.04	−0.29	Valley Falls	10.92	Saint Francis	0.23
Kentucky	78.3	+4.4	Beaver Dam	108	24	Farmers	45	17	2.30	−1.92	Richmond	5.54	Blandville	0.26
Louisiana	83.4	+3.2	Liberty Hill	108	30	2 stations	60	1†	2.51	−2.69	Robeline	6.40	2 stations	0.40
Maryland and Del	72.3	+1.5	Cumberland	110	25	Deer Park	26	17	3.86	−0.11	Princess Anne	10.60	Delaware City	1.27
Michigan	63.6	+0.6	Mount Clemens	99	9	Chatham	24	16	2.26	+0.88	Adrian	10.83	St. Ignace	1.23
Minnesota	64.6	+0.1	Farmington	97	8	Roseau	28	19	8.11	+4.16	Grand Meadow	14.45	Winton	1.45
Mississippi	83.3	+4.7	Columbus	108	26	Duck Hill	59	29	2.33	−1.97	Shubuta	6.99	Clarksdale	T.
Missouri	79.3	+6.2	2 stations	106	23†	2 stations	43	17	2.37	−2.29	Kidder	7.31	St. Louis (1)	0.10
Montana	58.4	−1.0	Chinook	101	2	Bowen	24	22	3.78	+1.45	Poplar	8.62	Belton	1.49
Nebraska	72.3	+3.0	Ewing	106	20	Harrison	36	29	4.60	+0.77	Cairo	12.10	Harrison	0.38
Nevada	62.0	−3.1	Leeland	114	14	Elko	12	6	1.26	+0.83	Rebel Creek	3.91	Pahrump	0.09
New England	62.7	−1.7	Norfolk, Mass	97	25	Patten, Me	24	4	2.32	−0.97	Presque Isle, Me	4.80	Provincetown, Mass.	0.55
New Jersey	68.5	−0.8	3 stations	98	8†	Woodbine	35	17†	2.66	−1.17	Belvidere	4.85	Woodbine	1.09
New Mexico	69.5	+0.3	Lordsburg	106	29	Elizabethtown	25	9	1.91	+0.45	Pinos Altos (near)	5.21	Los Lunas	0.10
New York	63.6	−0.9	Mount Hope	99	25	4 stations	29	6†	3.27	−0.39	Adams Center	7.30	Oswego	1.36
North Carolina	77.2	+3.6	Greensboro	104	11	Banners Elk	47	1	3.28	−1.91	Rockingham	7.80	Settle	0.95
North Dakota	62.2	−0.9	3 stations	93	2	Hannah	29	19	6.26	+2.82	Carson	13.28	Pembina	2.43
Ohio	71.1	+1.9	Syracuse	104	25	2 stations	32	17	3.14	−0.68	2 stations	6.33	2 stations	1.15
Oklahoma	81.1	+5.4	Newkirk	109	19	Kenton	46	9	0.99	−3.09	Pawhuska	3.98	.....do	0.00
Oregon	59.0	−0.7	Umatilla (2)	102	16†	Cliff	14	5	2.01	+0.32	Headworks	5.39	Hermiston	0.22
Pennsylvania	68.5	+0.6	Uniontown	101	11	Pocono Pines	25	6	3.75	−0.41	Somerset	7.05	Erie	1.17
Porto Rico	77.5	−0.8	3 stations	94	7†	Aibonito	54	2†	5.93	−0.95	Rio Grande (El Verde)	24.34	Hac. Isidora	0.41
South Carolina	81.1	+3.4	Blackville	108	25	Trenton	50	18	3.80	−1.25	Ferguson	7.67	Clemson College	0.26
South Dakota	67.5	+1.6	Cottonwood	101	25	Camp Crook	33	7	5.03	+2.30	De Smet	13.66	Custer	1.04
Tennessee	80.4	+6.3	2 stations	108	25†	Rugby	45	1	2.53	−2.15	Liberty	7.62	Covington	T.
Texas	81.1	+1.3	.....do	107	28†	Spur	48	3	1.47	−1.58	Sonora	8.16	15 stations	0.00
Utah	62.2	−2.2	4 stations	104	26†	East Portal	11	7	2.03	+1.42	Erekson	4.42	Hurricane	0.45
Virginia	74.0	+2.6	Ivor	103	12	Dale Enterprise	40	3	2.68	−1.91	Swetnam	6.90	Max Meadows	0.21
Washington	59.6	−1.0	Eltopia	107	16	2 stations	25	21†	1.94	+0.34	Cedar Lake	7.30	Fort Simcoe	0.01
West Virginia	72.0	+3.0	Point Pleasant	104	24	Bayard	30	17	3.00	−1.71	Cortland	5.98	Bluefield	0.62
Wisconsin	64.0	−0.9	Sheboygan (3)	93	8†	Sturgeon Bay	29	16	6.98	+3.63	Hancock	11.75	Prairie du Sac	3.27
Wyoming	57.3	+0.2	Fort Laramie	100	19	2 stations	18	7†	1.49	−0.29	Alta	4.03	Wheatland	T.

† Other dates also.

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

In cases where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Am unts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart V.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VI.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction t_0-t, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII.—Depth of snow on ground at end of the month, expressed in inches and tenths.

Charts VII and VIII are published only when the general snow cover is sufficiently extensive to justify their preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, June, 1914.*

Districts and stations.	Elevation of instruments. Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Pressure in inches. Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Temperature of the air, in degrees Fahrenheit. Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches. Total.	Departure from normal.	Days with 0.01 or more.	Wind. Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Direction.	Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
New England.							**62.6**	**− 1.0**										**70**	**2.21**	**− 0.9**										**5.3**		
Eastport	76	67	85	29.82	29.90	−0.03	55.4	+ 1.0	86	11	64	39	9	47	32	50	46	77	3.23	0.0	11	6,170	s.	40	nw.	5	8	15	7	5.6	....	....
Greenville	1,070	6	....	28.75	29.91	......	56.3	......	86	24	67	32	4	46	42	....	....	....	3.34	......	14	......	se.	....	....	....	....	....	....	....	....	....
Portland, Me	103	82	117	29.82	29.94	− .01	61.8	− 0.8	91	25	71	43	6	53	42	53	47	62	2.34	− 1.0	7	6,993	nw.	36	nw.	5	11	10	9	5.2	....	....
Concord	288	70	79	29.64	29.94	− .02	62.8	− 1.6	92	24	75	40	7	51	44	....	....	....	2.39	− 1.0	8	4,200	nw.	25	nw.	5	14	7	9	4.8	....	....
Burlington	404	11	48	29.51	29.94	− .02	62.0	− 1.8	90	24	72	42	20	52	37	....	....	....	3.30	0.0	9	6,510	s.	38	s.	19	7	14	9	5.6	....	....
Northfield	876	12	60	29.01	29.95	− .01	58.2	− 4.5	88	24	70	35	7	46	47	55	52	76	2.85	− 0.4	11	5,231	s.	35	n.	24	9	13	8	5.4	....	....
Boston	125	115	188	29.81	29.95	− .01	67.3	+ 1.5	94	25	76	49	9	58	36	58	53	64	1.40	− 1.6	7	7,393	sw.	32	nw.	16	8	16	6	5.2	....	....
Nantucket	12	14	90	29.95	29.96	− .02	60.7	− 0.6	82	11	68	48	9	54	27	56	53	79	2.58	+ 0.2	8	10,650	sw.	37	s.	4	9	16	5	4.8	....	....
Block Island	26	11	46	29.94	29.97	.00	61.8	+ 0.2	82	25	68	49	9	56	20	57	54	81	1.91	− 1.0	8	10,935	sw.	46	nw.	20	9	13	8	5.3	....	....
Narragansett	....	9	....	....	....	....	62.7	− 1.5	90	25	71	44	6	54	29	....	....	....	1.12	....	8	....	sw.	....	....	....	22	5	3	....	....	....
Providence	160	215	251	29.79	29.96	− .01	66.0	− 2.3	92	25	76	48	9	56	33	58	52	63	0.58	− 2.6	8	9,211	nw.	52	nw.	16	8	15	7	5.2	....	....
Hartford	159	122	140	29.79	29.96	− .01	66.4	− 0.7	91	24	76	47	20	57	32	58	52	63	1.70	− 1.4	12	5,513	s.	28	nw.	16	8	11	11	5.8	....	....
New Haven	106	117	155	29.86	29.97	.00	66.2	− 0.7	93	25	75	48	20	57	28	58	53	66	2.07	− 1.1	10	5,830	s.	35	nw.	16	9	10	11	5.6	....	....
Middle Atlantic States.							**70.9**	**+ 0.8**										**63**	**2.84**	**− 0.9**										**5.1**		
Albany	97	102	115	29.85	29.95	− .02	66.7	− 1.2	92	24	77	45	20	56	32	58	52	63	1.59	− 2.2	11	5,985	s.	30	s.	19	15	10	5	4.0	....	....
Binghamton	871	10	69	29.06	29.98	+ .01	65.1	− 1.1	90	24	76	40	6	54	39	....	....	....	5.21	+ 1.6	11	3,723	nw.	30	nw.	24	11	13	6	5.2	....	....
New York	314	414	454	29.64	29.97	− .01	67.6	− 0.9	90	25	76	48	20	60	26	59	52	63	1.83	− 1.4	12	11,031	nw.	56	nw.	20	9	8	13	5.9	....	....
Harrisburg	374	94	104	29.60	30.00	+ .01	71.2	+ 0.9	94	8	81	49	20	61	29	61	55	60	3.13	− 0.4	10	4,394	s.	30	n.	24	6	13	11	5.7	....	....
Philadelphia	117	123	190	29.87	30.00	+ .02	72.0	+ 0.8	94	25	81	51	20	63	29	63	57	65	3.70	+ 0.4	10	6,645	nw.	32	nw.	16	9	11	10	5.4	....	....
Reading	325	81	98	29.65	29.99	......	70.2	......	93	24	80	47	6	60	32	61	55	61	2.51	......	10	4,678	se.	33	n.	24	9	8	13	5.8	....	....
Scranton	805	111	119	29.15	30.00	+ .02	66.8	− 0.4	92	24	77	42	6	56	36	61	57	71	3.05	− 0.5	10	4,793	nw	36	nw.	7	11	12	7	4.7	....	....
Atlantic City	52	37	48	29.94	30.00	+ .02	68.3	+ 1.5	93	12	75	50	6	62	28	61	57	72	2.25	− 0.8	11	5,031	sw.	31	s.	28	8	10	12	5.8	....	....
Cape May	18	13	49	30.00	30.02	+ .04	68.3	+ 0.6	95	12	76	50	6	61	32	63	60	78	2.51	− 0.5	11	5,324	s.	30	se.	28	11	16	3	4.4	....	....
Trenton	190	159	183	29.77	29.97	......	69.4	......	92	24	80	49	17	59	31	60	54	65	1.74	− 1.8	10	7,105	nw.	36	w.	30	11	8	11	5.5	....	....
Baltimore	123	100	113	29.87	30.00	+ .01	74.4	+ 1.4	96	12	83	55	17	66	28	64	58	60	1.64	− 2.2	11	4,740	s.	34	n.	24	12	12	6	4.8	....	....
Washington	112	62	85	29.88	29.99	− .01	73.8	+ 1.1	97	24	84	51	3	64	31	64	60	66	6.20	+ 2.0	11	4,477	s.	44	nw.	4	11	13	6	5.0	....	....
Lynchburg	681	153	188	29.27	30.00	− .01	76.6	+ 3.1	101	25	88	51	17	65	35	66	61	64	2.21	− 1.7	7	4,596	w.	36	nw.	27	3	22	5	5.8	....	....
Mount Weather	1,725	10	75	28.21	29.98	− .02	68.9	+ 1.3	92	10	78	48	20	60	32	60	55	70	3.87	− 0.9	12	10,090	nw.	58	w.	27	1	16	13	6.9	....	....
Norfolk	91	170	205	29.92	30.01	+ .01	75.0	+ 0.6	97	12	84	57	6	66	27	67	64	71	3.20	− 1.1	14	8,224	sw.	38	sw.	12	8	18	4	4.7	....	....
Richmond	144	11	52	29.86	30.00	− .01	75.8	+ 0.7	100	12	87	52	3	64	34	67	62	66	2.76	− 0.8	11	5,068	s.	31	nw.	27	16	11	3	3.7	....	....
Wytheville	2,293	40	47	27.70	29.99	− .01	72.4	+ 3.7	94	26	85	50	3	60	33	65	61	72	0.60	− 3.5	8	3,328	w.	23	w.	28	21	6	3	2.8	....	....
South Atlantic States.							**79.3**	**+ 3.3**										**74**	**3.09**	**− 1.8**										**5.0**		
Asheville	2,255	70	84	27.76	30.03	+ .02	73.1	+ 4.4	92	25	84	51	18	62	28	66	62	75	5.34	+ 1.0	16	4,131	nw.	38	w.	12	9	16	5	5.0	....	....
Charlotte	773	68	76	29.20	30.02	+ .01	79.8	+ 4.3	102	25	90	57	18	69	29	69	64	68	2.12	− 2.3	12	4,332	ne.	34	w.	27	5	18	7	5.8	....	....
Hatteras	11	12	50	30.00	30.01	.00	75.5	+ 1.1	90	24	81	65	19	70	15	70	68	80	2.58	− 1.8	12	9,497	sw.	36	n.	22	10	16	4	4.6	....	....
Manteo	12	12	46	....	....	....	73.6	....	95	22	84	51	3	63	....	....	....	....	1.48	− 2.9	6	....	sw.	....	....	....	21	7	2	....	....	....
Raleigh	376	103	110	29.61	30.00	− .01	78.6	+ 3.5	100	25	89	59	17	68	29	69	64	69	3.42	− 1.3	11	5,032	sw.	48	w.	22	6	22	2	5.1	....	....
Wilmington	78	81	91	29.95	30.03	+ .02	78.0	+ 3.5	98	23	86	60	3	70	22	71	69	79	1.13	− 4.5	7	5,631	sw.	24	sw.	28	9	17	4	4.9	....	....
Charleston	48	11	92	29.97	30.02	+ .01	80.6	+ 2.1	101	24	87	66	19	74	26	74	72	79	4.33	− 1.1	12	7,108	s.	58	ne.	9	15	8	7	4.5	....	....
Columbia, S. C	351	41	57	29.64	30.02	+ .01	80.5	+ 2.3	103	24	91	60	18	70	32	70	66	70	6.31	+ 2.1	8	4,844	sw.	48	n.	28	14	12	4	4.4	....	....
Augusta	180	89	97	29.82	30.01	.00	82.6	+ 4.5	104	25	94	62	19	72	28	71	67	66	1.72	− 2.8	9	4,225	s.	36	ne.	28	12	11	7	5.2	....	....
Savannah	65	150	194	29.96	30.03	+ .02	81.6	+ 3.4	101	24	91	65	19	72	26	73	71	80	4.27	− 1.8	12	7,226	sw.	49	e.	9	12	12	6	4.9	....	....
Jacksonville	43	96	129	29.98	30.03	+ .02	82.8	+ 3.8	101	24	92	70	12	74	25	74	71	75	1.32	− 4.2	7	5,780	sw.	37	s.	16	9	16	5	5.4	....	....
Florida Peninsula.							**81.6**	**+ 1.1**										**75**	**2.78**	**− 4.0**										**4.6**		
Key West	22	10	64	30.01	30.03	+ .04	82.3	+ 0.1	90	27	87	71	21	77	18	74	71	71	1.04	− 3.2	9	5,854	se.	24	ne.	21	14	14	2	3.9	....	....
Miami	25	37	72	30.02	30.05	......	81.2	+ 0.8	90	18	87	68	3	75	17	74	71	72	2.57	− 5.3	9	5,106	se.	23	sw.	30	6	12	12	6.2	....	....
Sand Key	23	39	72	29.98	30.01	+ .02	81.0	......	88	20	83	71	5	79	9	76	74	79	0.14	......	2	7,456	e.	35	s.	29	20	9	1	3.1	....	....
Tampa	35	79	96	30.00	30.03	+ .02	81.2	+ 2.5	93	25	89	67	3	73	22	74	72	77	4.73	− 3.6	13	4,169	sw.	29	e.	29	8	16	6	5.3	....	....
Titusville	44	6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Gulf States.							**82.8**	**+ 4.7**										**70**	**2.85**	**− 1.7**										**4.0**		
Atlanta	1,174	190	216	28.83	30.04	+ .03	80.8	+ 5.2	100	25	91	58	19	70	25	69	64	62	2.14	− 1.7	8	6,142	nw.	36	w.	14	19	4	7	3.9	....	....
Macon	370	78	87	29.62	30.00	− .01	82.8	+ 5.7	103	25	94	62	18	71	28	72	68	67	2.18	− 1.4	10	3,674	s.	31	w.	14	13	14	3	4.0	....	....
Thomasville	273	8	57	29.73	30.02	+ .02	83.2	+ 3.7	101	24	96	66	20	71	30	73	70	74	2.62	− 2.1	11	3,398	sw.	32	e.	29	11	15	4	4.6	....	....
Pensacola	56	140	182	29.96	30.02	+ .03	82.2	+ 2.2	94	15	88	71	16	76	23	75	73	77	3.57	− 1.3	5	7,636	sw.	44	e.	16	12	13	5	4.7	....	....
Anniston	741	9	57	29.26	30.04	+ .04	81.2	+ 6.2	103	26	94	61	29	68	39	....	....	....	2.25	− 1.6	11	2,944	s.	34	ne.	10	15	12	3	3.6	....	....
Birmingham	700	11	48	29.28	30.03	+ .04	81.9	+ 3.7	100	26	93	64	19	71	32	71	67	67	4.49	+ 0.6	7	3,474	nw.	33	n.	15	18	8	4	3.7	....	....
Mobile	57	125	161	29.96	30.02	+ .03	83.7	+ 4.6	101	26	92	71	15	75	26	75	72	76	5.78	− 0.2	12	5,801	sw.	44	nw.	15	14	15	1	3.8	....	....
Montgomery	223	100	112	29.77	30.01	+ .01	84.0	+ 4.9	104	26	95	65	19	73	27	73	69	66	1.82	− 2.4	8	3,896	s.	39	ne.	15	18	10	2	3.4	....	....
Meridian	375	85	93	29.62	30.00	+ .02	83.6	+ 6.3	102	26	95	67	1	72	33	73	69	68	0.63	− 4.0	4	3,074	sw.	25	sw.	27	11	14	5	4.8	....	....
Vicksburg	247	62	74	29.75	30.02	+ .05	83.3	+ 4.8	99	10	93	67	17	74	28	74	71	71	2.31	− 2.2	5	3,411	sw.	34	e.	10	23	5	2	2.7	....	....
New Orleans	51	90	121	29.96	30.01	+ .03	84.2	+ 4.6	98	28	93	70	3	76	22	76	73	75	3.51	− 2.6	10	4,683	sw.	33	sw.	3	12	14	4	4.5	....	....
West Gulf States.							**82.4**	**+ 3.4**										**69**	**0.73**	**− 3.0**										**3.4**		
Shreveport	249	77	93	29.74	30.00	+ .04	83.9	+ 4.3	101	30	94	70	1	74	25	74	70	69	2.29	− 1.3	4	4,066	s.	23	e.	10	23	6	1	2.9	....	....
Bentonville	1,303	11	44	28.65	29.98	+ .04	79.1	+ 5.0	97	19	91	59	17	68	35	....	....	....	1.40	− 3.2	5	2,715	s.	25	s.	29	18	10	2	3.1	....	....
Fort Smith	457	79	94	29.49	29.96	+ .02	83.0	+ 6.2	102	28	94	65	17	72	35	71	66	59	0.38	− 3.6	3	4,106	s.	35	w.	29	19	7	4	3.1	....	....
Little Rock	357	139	147	29.61	29.98	+ .02	84.0	+ 6.8	101	27	94	64	17	74	28	72	67	60	0.01	− 4.1	1	6,035	s.	27	s.	15	18	11	1	3.2	....	....
Brownsville	57	3	40	......	......	......	82.6	......	96	29	91	71	11	74	21	....	....	....	0.63	......	4	......	s.	....	....	....	....	....	....	....	....	....
Corpus Christi	20	69	77	29.98	30.00	+ .09	81.6	+ 1.0	89	10	86	74	11	77	13	76	75	83	0.04	− 2.7	2	9,797	se.	30	se.	22	12	18	0	3.9	....	....
Dallas	512	109	117	29.45	29.98	......	83.6	......	101	28	92	69	1	75	24	....	....	....	2.86	......	3	6,430	se.	27	se.	7	14	15	1	3.8	....	....
Fort Worth	670	106	114	29.25	29.95	+ .03	83.0	+ 2.9	101	28	92	67	16	74	26	71	65	62	2.97	0.0	4	7,204	s.	30	s.	10	12	15	3	3.7	....	....
Galveston	54	106	114	29.97	30.03	+ .08	82.3	+ 1.4	94	29	87	73	22	78	17	75	73	78	0.12	− 4.6	1	6,459	s.	28	n.	18	20	10	0	2.8	....	....
Houston	138	111	121	29.86	30.00	......	83.2	+ 2.2	98	29	92	72	2	74	24	....	....	....	0.95	......	7	4,789	se.	25	se.	29	15	13	2	4.0	....	....
Palestine	510	64	72	29.46	29.98	+ .04	82.5	+ 4.1	98	29	92	67	1	73	23	73	70	72	T.	− 4.0	0	4,400	s.	15	s.	7	22	6	2	3.2	....	....
San Antonio	701	80	91	29.27	29.98	+ .08	82.0	+ 1.6	96	29	91	70	13	73	26	73	69	72	0.01	− 3.0	1	4,083	se.	18	se.	30	17	12	1	3.4	....	....
Taylor	583	55	63	29.41	30.02	+ .10	81.6	+ 1.6	98	28	91	68	13	72	26	....	....	....	0.09	− 3.4	1	6,315	s.	26	se.	7	12	16	2	4.3	....	....

TABLE I.—*Climatological data for United States Weather Bureau stations, June, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.												Precipitation, inches.			Wind.										
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Ohio Valley and Tennessee.							**76.5**	**+ 3.3**										**63**	**2.85**	**− 1.4**										**4.7**		
Chattanooga	762	189	213	29.23	30.02	+ .02	80.5	+ 5.1	98	26	92	58	19	70	28	69	64	64	2.25	− 2.1	8	4,889	sw.	37	n.		1	10	17	3	4.5	......	....
Knoxville	996	93	100	28.98	30.01	+ .01	79.4	+ 6.0	99	27	90	56	18	68	27	69	64	65	3.91	− 0.3	8	3,191	sw.	32	n.		12	12	12	6	4.9	......	....
Memphis	399	76	97	29.60	30.02	+ .05	84.2	+ 6.5	99	27	93	64	17	75	23	72	67	60	0.12	− 4.2	1	5,277	sw.	32	nw.		15	20	8	2	2.5	......	....
Nashville	546	168	191	29.45	30.02	+ .03	81.8	+ 5.5	100	25	93	60	18	71	32	70	64	61	2.95	− 1.4	7	5,024	sw.	65	nw.		15	15	12	3	4.0	......	....
Lexington	989	75	102	28.96	30.00	.00	75.8	+ 2.6	99	27	86	53	17	65	29	.....	.....	.....	4.77	+ 0.8	8	5,982	sw.	40	nw.		25	14	13	3	4.0	......	....
Louisville	525	219	255	29.44	30.02	+ .04	78.9	+ 3.9	101	27	89	55	17	68	28	68	63	61	2.20	− 2.0	5	7,301	sw.	34	n.		1	9	17	4	4.7	......	....
Evansville	431	72	82	29.53	29.99	+ .02	80.0	+ 4.7	100	24	90	57	16	70	28	69	64	63	3.99	− 0.2	8	4,679	sw.	46	ne.		13	9	20	1	4.5	......	....
Indianapolis	822	154	164	29.13	30.00	+ .03	74.8	+ 2.4	97	24	85	49	16	64	31	64	58	58	3.65	− 0.7	8	6,484	sw.	35	sw.		4	7	20	3	5.2	......	....
Terre Haute	575	96	129	29.38	29.98	......	77.2	......	100	24	88	48	16	66	29	66	60	59	1.41	......	5	6,506	sw.	29	sw.		21	3	24	3	5.7	......	....
Cincinnati	628	152	160	29.34	30.00	+ .01	76.2	+ 2.5	100	27	87	52	20	66	31	66	60	61	2.20	− 1.8	9	4,697	sw.	27	nw.		25	11	16	3	4.6	......	....
Columbus	824	173	222	29.16	30.01	+ .02	72.6	+ 1.6	97	24	84	45	20	61	35	63	58	64	2.03	− 1.5	7	6,994	sw.	55	nw.		4	11	12	7	4.7	......	....
Dayton	899	181	216	29.06	29.99	......	73.0	+ 0.8	97	27	84	46	20	62	37	64	58	65	2.17	− 1.8	9	6,654	ne.	45	n.		4	10	11	9	5.4	......	....
Pittsburgh	842	353	410	29.11	30.00	+ .01	71.0	− 0.1	93	24	81	45	17	61	31	61	54	59	3.31	− 0.6	7	7,316	nw.	53	nw.		27	10	10	10	5.3	......	....
Elkins	1,940	41	50	28.02	30.01	+ .01	69.5	+ 2.9	95	10	83	37	17	56	44	61	58	72	4.23	− 0.8	11	2,498	w.	29	w.		22	6	14	10	5.9	......	....
Parkersburg	638	77	84	29.38	30.03	+ .03	73.4	+ 1.9	97	25	85	48	20	62	38	64	59	66	2.16	− 2.5	8	3,698	n.	57	nw.		22	15	12	3	4.0	......	....
Lower Lake Region.							**66.1**	**− 0.9**										**67**	**2.51**	**− 1.1**										**4.8**		
Buffalo	767	247	280	29.17	30.00	+ .03	63.2	− 1.9	80	18	70	43	20	56	26	58	54	74	1.72	− 1.4	10	9,640	sw.	46	w.		24	10	12	8	5.2	......	....
Canton	448	10	61	29.48	29.95	......	61.0	− 4.8	87	24	72	36	6	50	42	.....	.....	.....	2.29	− 1.1	10	7,338	sw.	28	nw.		19	20	5	5	3.4	......	....
Oswego	335	76	91	29.60	29.96	− .01	61.3	− 2.5	86	24	69	44	20	54	30	55	51	71	1.36	− 2.1	9	6,490	w.	28	sw.		24	14	9	7	4.5	......	....
Rochester	523	86	102	29.43	30.00	+ .03	65.4	− 0.7	92	9	75	41	20	56	32	57	50	61	1.71	− 1.4	13	5,812	w.	27	w.		24	15	6	9	4.5	......	....
Syracuse	597	97	113	29.35	29.99	+ .02	64.4	− 2.5	88	24	73	41	20	56	30	58	53	68	4.40	+ 0.5	13	7,626	nw.	49	sw.		24	17	6	7	4.1	......	....
Erie	714	92	102	29.24	30.00	+ .02	66.0	− 1.0	92	24	73	45	17	59	24	59	55	68	1.17	− 2.6	9	6,107	w.	25	n.		29	8	16	6	5.0	......	....
Cleveland	762	190	201	29.20	30.01	+ .03	68.3	+ 0.4	93	24	76	48	26	60	29	61	57	69	2.80	− 0.9	9	7,805	se.	42	n.		15	6	19	5	5.1	......	....
Sandusky	629	62	103	29.34	30.01	+ .03	69.8	+ 1.0	95	9	78	50	17	61	34	62	57	65	3.13	− 0.7	11	7,531	sw.	37	ne.		15	5	16	9	5.7	......	....
Toledo	628	208	246	29.34	30.02	+ .05	69.9	+ 0.5	95	8	79	45	20	60	29	61	56	64	3.29	− 0.1	12	8,924	sw.	37	sw.		24	13	12	5	4.1	......	....
Fort Wayne	856	113	124	29.09	30.00	......	70.4	+ 1.9	96	21	82	43	20	59	35	63	58	67	2.39	......	9	5,849	sw.	41	nw.		26	7	18	5	5.2	......	....
Detroit	730	218	258	29.23	30.01	+ .04	68.0	+ 0.2	94	8	77	43	20	59	27	59	53	63	3.25	− 0.6	11	7,592	w.	35	w.		24	8	13	9	5.6	......	....
Upper Lake Region.							**62.5**	**− 0.1**										**71**	**4.75**	**+ 1.4**										**5.3**		
Alpena	609	13	92	29.35	30.02	+ .06	59.6	− 0.7	94	9	69	36	20	50	33	55	50	72	2.79	− 0.8	10	7,606	nw.	46	e.		28	2	20	8	5.8	......	....
Escanaba	612	54	60	29.34	30.00	+ .06	59.0	− 1.6	92	9	68	36	20	50	30	54	50	74	4.35	+ 0.8	11	7,494	s.	40	ne.		28	10	10	10	5.8	......	....
Grand Haven	632	54	92	29.32	29.99	+ .03	63.8	− 0.9	82	27	73	41	16	55	30	58	53	70	8.16	+ 5.6	10	6,710	w.	33	nw.		28	13	8	9	4.5	......	....
Grand Rapids	707	70	87	29.25	30.00	+ .03	67.6	− 0.5	91	8	78	42	16	57	32	60	55	65	6.13	+ 3.6	10	4,020	w.	32	w.		24	8	13	9	5.6	......	....
Houghton	684	62	72	29.26	29.98	+ .04	59.1	− 0.3	94	8	69	39	20	49	32	.....	.....	.....	3.97	+ 0.5	13	6,496	se.	40	e.		27	11	12	7	4.8	......	....
Lansing	878	11	62	29.08	30.00	......	66.0	− 1.4	92	8	78	37	20	54	34	59	55	69	4.11	+ 0.7	10	3,306	sw.	19	se.		26	10	11	9	5.3	......	....
Ludington	637	60	66	29.31	30.00	......	60.2	......	79	9	69	38	20	52	27	56	52	73	7.39	......	14	6,852	s.	46	w.		24	10	12	8	5.0	......	....
Marquette	734	77	111	29.22	30.03	+ .09	58.8	+ 0.3	97	7	69	34	19	49	36	52	46	65	4.21	+ 0.7	16	6,443	nw.	36	nw.		11	9	8	13	5.8	......	....
Port Huron	638	70	120	29.32	30.01	+ .04	64.3	+ 0.5	94	8	74	39	20	55	30	58	54	69	1.60	− 1.6	8	6,614	sw.	36	n.		19	10	14	6	5.1	......	....
Saginaw	641	48	82	29.32	30.01	......	65.6	......	94	8	77	40	16	55	32	61	58	75	3.89	+ 1.2	9	5,398	w.	32	nw.		24	12	10	8	5.1	......	....
Sault Ste. Marie	614	11	61	29.33	30.02	+ .06	58.0	+ 0.4	92	8	70	35	20	46	35	52	46	69	2.72	0.0	12	5,923	w.	34	nw.		15	10	11	9	5.2	......	....
Chicago	823	140	310	29.13	30.00	+ .04	70.2	+ 3.9	95	9	78	51	16	62	28	62	58	69	3.53	− 0.1	12	8,532	ne.	40	nw.		21	11	13	6	4.5	......	....
Green Bay	617	109	144	29.32	29.98	+ .03	64.3	− 0.8	88	8	73	42	16	56	31	58	54	72	8.68	+ 5.1	15	7,703	s.	48	sw.		24	6	11	13	6.6	......	....
Milwaukee	681	125	139	29.27	30.00	+ .05	64.4	+ 0.9	90	9	73	45	16	56	33	58	53	71	6.05	+ 2.4	14	5,755	ne.	39	nw.		24	9	12	9	5.4	......	....
Duluth	1,133	11	47	28.77	29.98	+ .06	57.0	− 0.7	82	10	66	39	20	48	28	54	51	81	6.28	+ 1.8	17	9,373	ne.	62	ne.		27	8	15	7	5.2	......	....
North Dakota.							**63.2**	**− 0.5**										**74**	**7.84**	**+ 4.2**										**5.8**		
Moorhead	940	8	57	28.93	29.93	+ .03	64.8	+ 0.5	85	7	75	41	19	54	35	60	57	78	8.92	+ 4.8	17	5,612	se.	38	e.		26	13	10	7	4.5	......	....
Bismarck	1,674	8	57	28.16	29.92	+ .05	64.0	− 0.2	84	2	74	40	19	54	32	58	54	74	9.90	+ 6.4	19	7,447	e.	53	e.		25	9	9	12	5.7	......	....
Devils Lake	1,482	11	44	28.35	29.90	+ .02	61.6	− 1.0	85	2	72	38	19	51	34	56	51	72	5.84	+ 2.3	15	8,282	ne.	50	sw.		6	7	11	12	6.3	......	....
Williston	1,872	40	47	27.92	29.87	+ .01	62.2	− 1.3	89	2	73	42	10	52	34	55	51	72	6.68	+ 3.1	17	5,858	se.	50	n.		3	3	15	12	6.6	......	....
Upper Mississippi Valley.							**73.6**	**+ 2.7**										**66**	**4.56**	**+ 0.2**										**5.1**		
Minneapolis	918	102	208	......	......	......	66.8	......	88	3	76	45	19	58	29	.....	.....	.....	8.63	+ 4.6	21	8,426	se.	67	nw.		23	9	8	13	6.0	......	....
St. Paul	837	201	236	29.03	29.93	+ .01	66.2	− 1.2	88	3	75	46	19	57	28	60	56	72	6.49	+ 2.1	20	8,971	se.	56	nw.		23	6	15	9	5.7	......	....
La Crosse	714	11	48	29.19	29.95	+ .02	68.3	+ 0.1	89	3	78	49	20	59	30	.....	.....	.....	9.78	+ 5.4	17	3,371	se.	36	nw.		24	6	8	16	6.5	......	....
Madison	974	70	78	28.96	29.99	+ .05	66.6	− 0.7	87	23	76	42	20	58	29	61	56	71	3.46	− 0.6	14	6,251	sw.	39	n.		24	8	12	10	6.0	......	....
Charles City	1,015	10	49	28.89	29.94	+ .03	69.2	+ 0.4	91	21	79	46	17	59	30	63	60	76	5.85	+ 0.8	18	5,332	se.	30	ne.		5	8	19	3	5.0	......	....
Davenport	606	71	79	29.31	29.96	+ .02	72.4	+ 1.5	96	21	82	45	20	62	38	64	60	66	8.84	+ 4.7	12	5,952	e.	40	w.		27	9	11	10	5.5	......	....
Des Moines	861	84	97	29.02	29.91	− .01	74.4	+ 4.0	95	24	84	52	20	64	38	65	60	65	3.89	− 1.1	10	6,764	sw.	48	sw.		6	6	18	6	5.6	......	....
Dubuque	698	81	96	29.24	29.98	+ .05	69.8	+ 0.2	90	8	79	45	20	61	28	63	59	70	5.81	+ 1.3	15	4,615	s.	34	nw.		24	6	15	9	6.0	......	....
Keokuk	614	64	78	29.30	29.96	+ .02	76.8	+ 4.3	100	26	87	49	20	66	39	68	63	66	3.33	− 1.0	9	5,853	s.	32	w.		27	9	19	2	4.4	......	....
Cairo	356	87	93	29.60	29.97	.00	81.7	+ 6.5	100	27	92	62	16	72	26	70	66	63	0.92	− 3.4	5	5,310	sw.	30	nw.		11	15	9	6	4.2	......	....
Peoria	609	11	45	29.33	29.99	+ .04	74.2	+ 3.3	99	21	86	47	20	63	40	65	60	64	2.45	− 1.8	8	4,859	s.	26	w.		27	14	11	5	4.2	......	....
Springfield, Ill	644	10	91	29.30	29.97	+ .02	77.3	+ 5.0	100	26	89	50	16	66	39	66	60	58	1.69	− 2.6	7	6,010	sw.	25	w.		27	7	17	6	5.2	......	....
Hannibal	534	74	109	29.40	29.96	+ .01	78.4	+ 5.1	99	26	89	53	20	68	39	.....	.....	.....	2.60	− 0.9	7	7,139	sw.	36	sw.		27	14	11	5	4.2	......	....
St. Louis	567	265	303	29.37	29.96	+ .01	81.1	+ 6.0	101	26	91	57	20	71	36	68	62	54	0.10	− 4.4	3	8,999	sw.	44	sw.		27	19	9	2	3.4	......	....
Missouri Valley.							**74.6**	**+ 3.6**										**68**	**5.86**	**+ 1.5**										**4.4**		
Columbia, Mo	784	11	84	29.15	29.96	+ .01	78.8	+ 4.3	98	26	90	50	17	68	39	.....	.....	.....	3.14	− 1.2	9	5,817	s.	28	w.		27	9	13	8	5.0	......	....
Kansas City	963	161	181	28.92	29.92	.00	78.4	+ 5.4	96	26	88	58	17	69	34	68	63	63	5.51	+ 0.8	11	8,648	s.	48	n.		21	15	10	5	3.9	......	....
St. Joseph	967	11	49	28.91	29.91	......	78.2	......	97	20	88	55	17	69	35	68	64	67	5.40	......	8	6,431	s.	38	nw.		14	14	8	8	4.4	......	....
Springfield, Mo	1,324	98	104	28.62	29.98	+ .03	78.8	+ 6.5	97	19	89	57	16	69	30	68	62	61	1.48	− 3.7	5	6,944	s.	27	nw.		30	21	7	2	2.6	......	....
Iola	984	11	50	28.91	29.92	− .01	79.6	+ 6.2	98	26	90	57	17	69	36	.....	.....	.....	3.94	− 0.8	7	5,536	s.	34	nw.		30	17	10	3	3.4	......	....
Topeka	983	85	101	......	......	......	78.2	+ 4.7	98	20	88	57	17	68	35	.....	.....	.....	8.50	+ 3.7	10	8,333	s.	34	s.		8	13	11	6	4.0	......	....
Lincoln	1,189	11	84	28.65	29.87	− .03	75.2	+ 3.6	98	26	86	55	28	65	33	67	63	72	10.71	+ 6.4	17	8,197	s.	52	nw.		14	11	14	5	4.7	......	....
Omaha	1,105	115	121	28.74	29.89	− .02	75.2	+ 3.6	97	25	85	56	28	66	33	67	63	69	7.01	+ 2.0	12	6,104	s.	36	n.		25	10	15	5	4.4	......	....
Valentine	2,598	47	54	27.22	29.89	+ .03	69.8	+ 2.7	95	3	82	48	29	57	41	60	54	65	3.94	+ 0.1	14	7,860	se.	56	e.		12	17	8	5	3.6	......	....
Sioux City	1,135	94	164	28.69	29.87	− .03	72.6	+ 3.2	94	23	83	53	1	62	30	65	61	69	3.91	0.0	15	9,896	s.	67	s.		23	8	14	8	5.3	......	....
Huron	1,306	59	74	28.52	29.89	+ .01	68.0	+ 1.4	94	3	78	49	1	58	31	62	58	76	11.56	+ 7.8	15	8,432	se.	58	nw.		3	7	16	7	5.4	......	....
Pierre	1,572	70	75	28.26	29.89	+ .02	68.8	− 0.1	95	18	80	51	28	58	38	61	57	69	5.72	+ 2.6	16	8,068	e.	56	w.		26	7	19	4	4.9	......	....
Yankton	1,233	49	57	28.58	29.87	− .02	71.7	+ 2.3	94	21	82	50	28	61	34	.....	.....	.....	4.84	+ 0.6	10	6,789	ne.	46	w.		4	3	20	7	6.0	......	....

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TABLE I.—*Climatological data for United States Weather Bureau stations, June, 1914*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level, feet.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure in inches: Station, reduced to mean of 24 hours.	Pressure in inches: Sea level, reduced to mean of 24 hours.	Pressure in inches: Departure from normal.	Temperature of the air, in degrees Fahrenheit: Mean max. + mean min. ÷ 2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 or more.	Wind: Total movement, miles.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Northern Slope.							**61.9**	**- 0.2**										**62**	**2.70**	**+ 0.4**										**5.2**		
Havre	2,505	11	44	27.27	29.87	+ .02	60.7	- 1.7	93	1	72	39	11	49	40	54	48	67	4.07	+ 1.2	14	5,989	nw.	40	w.	22	12	8	10	5.7	.....	....
Helena	4,110	87	114	25.77	29.90	+ .05	58.3	- 2.3	91	18	69	38	6	48	37	49	43	62	3.63	+ 1.5	14	6,375	sw.	35	sw.	21	8	8	14	6.1	.....	....
Kalispell	2,962	11	34	26.89	29.92	+ .04	57.3	- 1.5	91	17	70	35	5	44	41	48	42	65	2.51	+ 0.8	10	3,272	w.	22	w.	1	8	16	6	5.3	.....	....
Miles City	2,371	26	48	27.40	29.90	+ .05	66.7	+ 0.7	94	1	80	41	7	54	37	57	50	63	3.44	+ 0.7	13	4,136	s.	34	n.	13	8	16	6	5.1	.....	....
Rapid City	3,259	50	58	26.55	29.89	+ .04	66.6	+ 2.8	91	18	79	48	7	55	33	56	49	59	3.07	- 0.5	16	6,571	n.	50	sw.	25	11	9	10	5.3	.....	....
Cheyenne	6,088	84	101	24.03	29.86	+ .02	61.4	- 0.1	85	19	74	41	7	48	40	50	41	53	0.25	- 1.3	7	8,697	s.	58	w.	26	8	17	5	5.3	.....	....
Lander	5,372	60	68	24.63	29.87	+ .02	60.8	- 0.5	91	18	76	29	7	45	45	48	36	47	0.18	- 0.9	7	4,764	w.	44	w.	20	12	15	3	4.5	.....	....
Sheridan	3,790	10	47	26.06	29.90	......	61.1	......	90	18	76	33	7	46	44	53	48	66	1.65	......	12	4,503	nw.	40	nw.	28	9	13	8	4.9	.....	....
Yellowstone Park	6,200	11	48	23.89	29.91	+ .05	53.4	- 2.6	80	1	66	32	22	41	37	44	38	63	2.48	+ 0.8	19	5,877	s.	42	sw.	5	8	11	11	5.8	T.	....
North Platte	2,821	11	51	27.03	29.89	+ .03	72.1	+ 3.7	98	10	85	48	9	59	39	63	59	70	4.63	+ 1.4	14	5,591	s.	27	sw.	4	18	8	4	3.5	.....	....
Middle Slope.							**75.9**	**+ 4.0**										**59**	**2.33**	**- 0.8**										**3.7**		
Denver	5,291	129	172	24.72	29.86	+ .02	68.6	+ 2.2	93	28	83	43	9	54	41	53	43	48	1.67	+ 0.2	8	5,599	sw.	33	sw.	6	18	9	3	3.2	.....	....
Pueblo	4,685	80	86	25.27	29.84	+ .01	70.6	+ 1.6	96	28	84	43	9	57	42	55	44	46	1.90	+ 0.4	4	4,644	nw.	31	w.	8	19	8	3	3.1	.....	....
Concordia	1,398	42	50	28.45	29.88	- .02	78.6	+ 5.9	102	26	90	54	17	68	37	68	63	64	2.73	- 2.2	12	6,692	s.	38	s.	6	7	16	7	5.4	.....	....
Dodge City	2,509	11	51	27.33	29.86	- .01	77.3	+ 4.2	98	28	88	58	27	66	36	67	62	67	3.82	+ 0.5	9	8,986	s.	47	se.	5	14	14	2	4.2	.....	....
Wichita	1,358	139	158	28.49	29.88	- .03	79.6	+ 5.3	99	19	90	58	17	69	33	69	64	65	3.83	- 0.9	7	11,178	s.	50	nw.	5	21	7	2	2.8	.....	....
Oklahoma	1,214	10	47	28.69	29.93	+ .02	80.8	+ 5.1	100	28	91	62	17	70	35	70	65	63	0.02	- 3.0	2	10,846	s.	42	se.	6	15	14	1	3.6	.....	....
Southern Slope.							**78.0**	**+ 0.8**										**62**	**1.84**	**- 1.0**										**3.8**		
Abilene	1,738	10	52	28.18	29.94	+ .06	79.3	+ 1.1	96	29	89	65	10	70	27	69	65	65	1.10	- 2.1	4	7,373	s.	32	s.	7	16	6	8	3.8	.....	....
Amarillo	3,676	10	49	26.27	29.90	+ .05	76.2	+ 4.2	99	26	88	57	17	64	33	64	58	62	0.84	- 2.2	4	10,429	sw.	40	s.	7	24	6	0	3.0	.....	....
Del Rio	944	64	71	28.96	29.93	+ .08	80.7	- 1.4	96	29	89	68	16	72	24	.....	.....	.....	3.98	+ 0.9	8	6,340	se.	36	n.	16	13	15	2	3.6	.....	....
Roswell	3,566	75	85	26.35	29.87	+ .07	75.8	- 0.5	98	29	88	58	1	64	31	63	56	60	1.45	- 0.6	7	6,394	s.	32	s.	7	14	13	3	4.6	.....	....
Southern Plateau.							**76.7**	**- 0.9**										40	**0.65**	**+ 0.3**										**2.8**		
El Paso	3,762	110	133	......	......	......	78.9	- 0.7	100	29	90	59	1	68	29	.....	.....	.....	1.47	+ 0.9	8	7,063	e.	58	se.	1	16	13	1	....	.....	....
Santa Fe	7,013	57	62	23.32	29.81	.00	67.0	+ 0.8	87	29	79	49	9	55	31	52	40	43	1.72	+ 0.7	5	5,676	se.	34	sw.	6	13	17	0	4.1	.....	....
Flagstaff	6,907	8	57	......	......	......	58.5	......	86	27	74	31	3	43	46	.....	.....	.....	1.29	......	8	......	sw.	48	sw.	6	16	7	7	....	.....	....
Phoenix	1,108	76	81	28.65	29.76	+ .02	84.6	+ 0.2	110	27	98	60	8	71	37	63	48	32	0.05	- 0.1	2	4,142	e.	28	ne.	30	20	5	5	2.7	.....	....
Yuma	141	9	58	29.62	29.76	+ .02	85.6	+ 0.9	114	27	102	58	8	69	41	66	54	41	T.	0	0	3,655	w.	21	s.	4	30	0	0	0.4	.....	....
Independence	3,910	11	42	25.95	29.88	+ .10	67.5	- 5.9	101	28	83	39	6	52	42	53	41	45	0.01	- 0.1	1	3,070	nw.	34	sw.	19	18	7	5	4.2	.....	....
Middle Plateau.							**63.3**	**- 1.9**										**46**	**1.43**	**+ 0.9**										**3.8**		
Reno	4,532	74	81	25.44	29.89	+ .03	61.6	+ 0.6	95	28	76	33	5	47	45	47	34	44	0.29	0.0	3	5,592	w.	36	w.	18	18	8	4	3.2	T.	....
Tonopah	6,090	12	20	24.05	29.86	......	62.2	......	92	29	74	30	5	50	33	47	32	41	0.58	+ 0.1	7	5,712	w.	40	nw.	25	14	14	2	4.2	.....	....
Winnemucca	4,344	18	56	25.58	29.91	+ .03	61.2	- 2.1	95	18	76	31	6	46	42	48	37	50	2.17	+ 1.5	9	4,159	ne.	25	sw.	4	13	7	10	4.4	0.1	....
Modena	5,479	10	43	24.59	29.84	+ .02	61.6	- 1.6	93	28	77	34	6	46	50	46	30	40	1.50	+ 1.1	6	9,103	sw.	52	sw.	24	17	7	6	3.2	T.	....
Salt Lake City	4,360	147	189	25.57	29.87	+ .02	64.9	- 3.4	92	18	76	32	6	54	32	53	43	51	2.68	+ 1.9	11	5,713	nw.	35	se.	24	17	10	3	3.8	2.0	....
Durango	6,546	18	56	23.71	29.88	+ .06	61.2	- 1.5	92	28	79	34	9	44	53	48	38	52	1.72	+ 0.9	6	......	nw.	28	ne.	30	15	11	4	3.3	.....	....
Grand Junction	4,602	82	96	25.35	29.88	+ .05	69.2	- 3.4	95	29	82	44	7	57	35	52	39	41	1.10	+ 0.7	12	6,207	se.	55	sw.	6	14	9	7	4.2	.....	....
Northern Plateau.							**61.7**	**- 3.2**										**54**	**1.44**	**+ 0.3**										**5.3**		
Baker	3,471	48	53	26.44	30.01	+ .06	55.3	- 3.3	92	17	67	30	5	43	40	47	40	64	1.67	+ 0.5	10	4,042	S.	19	n.	20	11	6	13	5.1	0.4	....
Boise	2,739	78	86	27.12	29.94	+ .03	63.0	- 3.0	96	18	75	35	5	51	36	50	40	51	0.82	- 0.1	8	3,844	nw.	24	nw.	4	11	4	15	5.4	T.	....
Lewiston	757	40	48	29.13	29.94	.00	65.6	- 3.5	96	17	78	40	5	54	39	.....	.....	.....	0.96	- 0.1	9	2,492	e.	23	nw.	18	11	6	13	5.1	.....	....
Pocatello	4,477	46	54	25.45	29.91	+ .04	60.4	- 3.8	90	18	73	32	5	48	38	49	40	55	3.23	+ 2.2	14	5,398	se.	33	sw.	4	12	10	8	4.7	1.0	....
Spokane	1,929	101	110	27.92	29.95	+ .01	60.9	- 2.5	90	16	72	40	5	50	36	50	40	53	0.86	- 0.8	8	4,982	sw.	25	sw.	21	9	6	15	6.1	.....	....
Walla Walla	1,000	57	65	28.90	29.96	.00	64.9	- 3.3	95	16	76	43	5	54	34	53	42	49	1.12	- 0.1	10	3,724	s.	20	sw.	3	10	7	13	5.3	.....	....
North Pacific Coast Region.							**56.8**	**- 0.8**										**77**	**1.94**	**- 0.1**										**5.7**		
North Head	211	11	56	29.86	30.08	+ .09	53.1	- 1.9	60	27	56	44	4	51	11	51	50	90	2.35	+ 0.6	15	11,973	nw.	46	s.	5	4	15	11	6.3	.....	....
Port Crescent	259	8	53	29.79	30.08	+ .05	52.2	- 1.2	76	14	60	37	4	44	29	.....	.....	.....	1.52	- 0.3	10	3,504	w.	14	ne.	6	5	17	8	5.8	.....	....
Seattle	125	215	250	29.92	30.05	+ .05	58.9	- 1.2	87	15	67	43	5	51	26	53	48	73	1.75	0.0	11	6,781	s.	36	sw.	21	6	11	13	6.0	.....	....
Tacoma	213	113	120	29.82	30.04	+ .01	58.6	- 0.8	88	15	67	40	4	50	31	52	48	71	1.77	- 0.4	8	4,821	n.	24	sw.	3	6	16	8	5.4	.....	....
Tatoosh Island	109	7	57	29.95	30.05	+ .03	52.2	- 0.8	63	14	56	44	4	49	16	50	49	92	2.94	- 1.2	15	7,566	s.	36	e.	6	8	10	12	6.1	.....	....
Portland, Oreg.	153	68	106	29.87	30.03	- .01	61.4	+ 0.1	94	15	70	42	4	52	33	54	50	70	1.52	- 0.3	11	4,565	nw.	21	w.	3	8	8	14	5.9	.....	....
Roseburg	510	9	57	29.50	30.04	+ .01	61.3	+ 0.4	94	14	73	38	21	49	45	53	47	67	1.76	+ 0.7	7	2,597	n.	20	nw.	4	12	13	5	4.2	.....	....
Middle Pacific Coast Region.							**60.5**	**- 2.1**										**66**	**0.79**	**+ 0.4**										**3.9**		
Eureka	62	73	89	30.01	30.08	+ .03	52.8	- 1.8	63	23	56	45	5	49	13	50	49	88	1.73	+ 0.7	9	5,756	n.	34	n.	3	6	8	16	6.6	.....	....
Mount Tamalpais	2,375	11	18	27.52	29.97	+ .02	60.2	- 3.9	89	28	68	39	5	52	31	51	42	55	0.45	0.0	2	11,470	nw.	74	nw.	4	19	8	3	2.7	.....	....
Point Reyes Light	490	7	18	29.43	29.95	......	51.2	- 1.6	62	26	54	44	5	48	13	.....	.....	.....	0.42	......	3	19,573	nw.	94	nw.	4	8	16	16	6.4	.....	....
Red Bluff	332	50	56	29.54	29.89	+ .01	72.8	- 2.9	108	17	86	47	5	60	39	57	45	45	1.43	+ 1.0	5	4,156	se.	23	se.	6	20	7	3	2.6	.....	....
Sacramento	69	106	117	29.84	29.90	+ .01	67.1	- 1.8	101	29	80	49	8	54	37	57	49	62	0.60	+ 0.4	4	6,933	s.	32	nw.	4	25	3	2	1.8	.....	....
San Francisco	155	200	204	29.80	29.97	+ .01	56.6	- 0.4	84	27	63	48	6	50	26	51	48	79	0.29	+ 0.1	3	7,974	w.	35	w.	29	12	13	5	4.1	.....	....
San Jose	141	12	110	29.83	29.98	......	62.5	- 2.5	93	28	75	44	9	50	39	.....	.....	.....	0.25	+ 0.2	4	4,620	nw.	26	nw.	4	18	10	2	3.3	.....	....
South Pacific Coast Region.							**65.6**	**- 0.5**										**68**	**0.14**	**0.0**										**3.4**		
Fresno	327	89	98	29.54	29.89	+ .04	73.6	- 2.2	106	29	89	50	8	58	39	57	43	4.2	+0.23	+ 0.1	2	6,826	nw.	30	nw.	5	21	7	2	2.4	.....	....
Los Angeles	338	159	191	29.58	29.94	+ .04	64.8	+ 0.3	88	28	74	52	12	56	27	58	54	76	0.09	0.0	1	3,850	s.	17	s.	5	15	8	7	4.3	.....	....
San Diego	87	62	70	29.84	29.94	+ .02	63.8	0.0	79	27	69	55	26	59	18	59	56	80	T.	0.0	0	4,804	w.	19	se.	5	24	5	1	2.8	.....	....
San Luis Obispo	201	47	54	29.78	30.00	+ .05	60.4	0.0	96	27	71	42	12	50	36	53	49	74	0.22	+ 0.1	2	4,053	nw	24	nw.	9	14	12	4	4.1	.....	....
West Indies.																																
San Juan	82	8	54	29.94	30.03	+ .04	78.6	......	88	26	83	71	1	74	16	.....	.....	.....	5.14	- 0.7	18	9,794	e.	32	ne.	29	5	12	13	6.2	.....	....
Panama.																																
Ancon	92	6	69	29.71	29.81	......	81.0	......	94	22	89	70	6	73	20	76	75	89	7.28	- 0.8	21	4,649	nw.	24	n.	8	1	11	18	7.6	.....	....
Culebra	404	5	62	29.42	29.83	......	80.0	......	90	27	87	70	6	73	19	75	74	94	8.06	- 0.8	23	4,270	nw.	28	e.	18	0	4	26	8.8	.....	....
Colon	10	5	71	29.82	29.84	......	80.5	......	88	17	84	74	18	77	11	77	76	87	16.30	+ 2.9	25	5,892	w.	33	w.	8	1	11	18	7.6	.....	....

Table II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1914, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex	15	3.55 p.m.	4.13 p.m.	0.67	3.58 p.m.	4.12 p.m.	.01	.24	.46	.66											
Albany, N. Y	19			0.24														.20			
Alpena, Mich	24			0.55														.52			
Amarillo, Tex	20	10.40 p.m.	11.45 p.m.	0.65	10.50 p.m.	11.18 p.m.	.01	.12	.15	.34	.54	.60	.63								
Anniston, Ala	3	8.40 p.m.	D. N. p.m.	0.70	10.37 p.m.	10.54 p.m.	.09	.30	.45	.52	.57										
Asheville, N. C	12	4.10 p.m.	5.40 p.m.	1.17	4.15 p.m.	4.46 p.m.	.01	.70	.89	.91	.94	1.02	1.09	1.12							
	28	2.20 p.m.	2.55 p.m.	0.76	2.34 p.m.	2.54 p.m.	.01	.20	.44	.67	.74										
Atlanta, Ga	18			0.86														.48			
Atlantic City, N. J	8			0.65														.40			
Augusta, Ga	18			0.99														.44			
Baker, Oreg	7			0.22														.19			
Baltimore, Md	25			0.50														.48			
Bentonville, Ark	30			0.84														.33			
Binghamton, N. Y	7	6.15 p.m.	7.55 p.m.	1.04	6.35 p.m.	7.12 p.m.	.08	.21	.30	.44	.57	.70	.81	.90	.93						
	24	6.55 p.m.	7.40 p.m.	0.82	7.08 p.m.	7.18 p.m.	.08†	.32†	.60†												
	28	8.13 p.m.	9.10 p.m.	0.57	8.18 p.m.	8.47 p.m.	.01	.14	.30	.39	.46	.50	.55								
Birmingham, Ala	15	7.39 p.m.	D. N. p.m.	1.43	7.42 p.m.	7.59 p.m.	.01	.36	.89	1.18	1.25										
	17	12.26 p.m.	4.20 p.m.	1.38	1.16 p.m.	2.17 p.m.	.03	.09	.28	.39	.51	.72	.83	.88	.94	.99	1.05	1.16	1.22		
Bismarck, N. Dak	4	9.05 p.m.	D. N. p.m.	1.01	9.09 p.m.	9.39 p.m.	.01	.24	.33	.41	.49	.58	.67								
	26–27	1.40 p.m.	6.44 a.m.	3.22	6.23 p.m.	6.51 p.m.	.20	.37	.73	1.00	1.12	1.23	1.31								
	29	2.08 p.m.	3.18 p.m.	0.56	2.15 p.m.	2.37 p.m.	.01			.40	.49	.52									
Block Island, R. I	4			1.11														.21			
Boise, Idaho	24			0.28														.16			
Boston, Mass	20			0.35														.29			
Buffalo, N. Y	19			0.53														.36			
Burlington, Vt	19			1.32														.78			
Cairo, Ill	1			0.37														.31			
Canton, N. Y	19			0.64														.24			
Charles City, Iowa	13	4.25 a.m.	2.08 p.m.	1.94	6.18 a.m.	6.44 p.m.	.12	.21	.32	.48	.67	.77	.80								
Charleston, S. C	18–19	6.40 p.m.	D. N. a.m.	1.68	6.45 p.m.	8.12 p.m.	.02	.09	.16	.23	.28	.37	.39	.42	.47	.52	.65	.79	1.21	1.42	
Charlotte, N. C	10	4.32 p.m.	5.42 p.m.	0.92	4.34 p.m.	5.18 p.m.	.01	.17	.36	.43	.50	.54	.67	.73	.83	.89					
Chattanooga, Tenn	13			0.23														.23			
Cheyenne, Wyo	1			0.13														.08			
Chicago, Ill	4			1.16														.58			
Cincinnati, Ohio	5			0.62														.43			
Cleveland, Ohio	21			0.46														.44			
Columbia, Mo	30–1[1]	6.50 p.m.	D. N. a.m.	1.85	8.23 p.m.	9.41 p.m.	.08	.10	.16	.23	.31	.35	.40	.45	.50	.57	.67	.78	1.03		
Columbia, S. C	5	5.20 p.m.	9.30 p.m.	1.56	5.50 p.m.	6.33 p.m.	.03	.30	.60	.90	1.01	1.11	1.21	1.31	1.40	1.43					
	18	10.25 a.m.	Noon.	0.68	11.30 p.m.	11.54 p.m.	.04	.10	.26	.38	.51	.64									
	28	3.55 p.m.	6.40 p.m.	2.67	5.02 p.m.	5.52 p.m.	.33	.12	.35	.60	1.01	1.29	1.57	1.84	2.02	2.11	2.18				
Columbus, Ohio	4			0.88														.46			
Concord, N. H	28–29			1.02														(*)			
Concordia, Kans	15			0.99														.34			
Corpus Christi, Tex	6			0.02														.02			
Dallas, Tex	17	11.00 a.m.	11.59 a.m.	1.76	11.15 a.m.	11.53 a.m.	.08	.07	.11	.14	.36	.74	.98	1.43	1.68						
Davenport, Iowa	4–5	7.22 p.m.			7.40 p.m.	8.02 p.m.	.05	.08	.30	.74	1.12	1.19									
					8.41 p.m.	9.27 p.m.	1.38	.21	.42	.54	.56	.59	.67	.73	.85	.93	.97				
					2.21 a.m.	3.00 a.m.	2.67	.21	.32	.41	.48	.59	.61	.66	.73						
			7.35 a.m.	4.33	4.08 a.m.	4.30 a.m.	3.48	.08	.27	.46	.57	.60									
Do	24	6.58 p.m.	about 10.00 p.m.	1.59	7.07 p.m.	7.40 p.m.	.01	.12	.33	.41	.43	.71	1.09	1.23							
Dayton, Ohio	10	4.35 p.m.	5.45 p.m.	0.84	4.43 p.m.	5.25 p.m.	.04	.05	.10	.17	.23	.32	.43	.58	.76	.79					
Del Rio, Tex	16	2.50 p.m.	8.45 p.m.	2.54	2.53 p.m.	3.33 p.m.	.01	.39	.72	1.16	1.54	1.80	1.94	2.00	2.06						
Denver, Colo	14–15			1.06														.28			
Des Moines, Iowa	25	D. N. a.m.	4.45 a.m.	1.22	1.42 a.m.	2.15 a.m.	.14	.19	.37	.50	.59	.67	.77	.84							
Detroit, Mich	4			1.18														.57			
Devils Lake, N. Dak	6	10.18 p.m.	D. N. p.m.	0.81	10.18 p.m.	10.37 p.m.	.00	.17	.47	.66	.72										
Dodge City, Kans	1	4.10 p.m.	6.30 p.m.	1.13	6.18 p.m.	6.28 p.m.	.80	.24	.32												
Dubuque, Iowa	4–5	5.58 p.m.	4.00 a.m.	1.85	7.19 p.m.	7.43 p.m.	.16	.12	.31	.59	.77	.82									
Duluth, Minn	8			0.95														.57			
Durango, Colo	1			1.05														(*)			
Eastport, Me	4–5			1.65														.33			
Elkins, W. Va	25	D. N. a.m.	D. N. a.m.	1.00	2.18 a.m.	2.53 a.m.	.01	.17	.33	.46	.50	.67	.89	.97							
El Paso, Tex																					
Erie, Pa	3–4			0.50														.22			
Escanaba, Mich	24	D. N. a.m.	5.45 a.m.	1.10	2.29 a.m.	3.09 a.m.	.02	.08	.14	.17	.26	.46	.64	.81	.86						
	27	12.20 p.m.	3.00 p.m.	0.90	12.40 p.m.	1.14 p.m.	.06	.11	.25	.39	.45	.54	.60	.67							
Eureka, Cal	24			0.26														.11			
Evansville, Ind	5	6.12 p.m.	7.28 p.m.	0.66	6.34 p.m.	6.53 p.m.	.06	.10	.30	.44	.51										
	13	5.39 p.m.	6.22 p.m.	0.97	5.41 p.m.	6.08 p.m.	.01	.17	.41	.61	.77	.93	.95								
	25	1.38 p.m.	3.09 p.m.	1.56	1.40 p.m.	2.41 p.m.	.01	.06	.41	.70	.85	1.02	1.17	1.23							
Flagstaff, Ariz	18			0.51														(*)			
Fort Smith, Ark	16			0.32														.28			
Fort Wayne, Ind	26			0.56														.48			
Forth Worth, Tex	16	3.08 a.m.	6.48 a.m.	0.91	4.29 a.m.	5.06 a.m.	.04	.09	.15	.24	.39	.54	.70	.84	.85						
	17	10.52 a.m.	12.25 p.m.	1.71	10.52 a.m.	11.12 a.m.	.00	.28	.69	.97	1.11										
Fresno, Cal	19			0.08														.08			
Galveston, Tex	22			0.12														.11			
Grand Haven, Mich	3–4	8.58 p.m.	8.45 a.m.	2.18	9.01 p.m.	9.21 p.m.	.01	.22	.50	.76	.85										
					6.13 a.m.	6.23 a.m.	1.50	.17	.35												
	21	4.50 p.m.	8.00 p.m.	2.57	5.08 p.m.	5.42 p.m.	.01	.15	.42	.74	.88	1.14	1.43	1.54							
					7.16 p.m.	7.40 p.m.	2.01	.08	.17	.33	.48	.55									
Do	22	D. N. a.m.	8.20 a.m.	0.76	6.49 a.m.	7.24 a.m.	.02	.06	.10	.16	.34	.57	.65	.70							
Grand Junction, Colo	15			0.14														.13			
Grand Rapids, Mich	21	11.00 a.m.	9.00 p.m.	2.47	4.32 p.m.	5.08 p.m.	.36	.09	.19	.26	.34	.41	.47	.56	.59						
					5.49 p.m.	6.49 p.m.	1.03	.22	.34	.40	.56	.70	.74	.80	.86	.99	1.12	1.29			
Green Bay, Wis	3–4	1.38 p.m.	9.10 a.m.	3.74	4.50 p.m.	6.26 p.m.	.55	.06	.11	.20	.25	.34	.51	.67	.68	.73	.83	1.33	1.63	2.08	
	6–7	6.05 p.m.	D. N. a.m.	1.12	9.51 p.m.	10.15 p.m.	.49	.05	.19	.35	.42	.46									
	27	12.35 a.m.	5.05 a.m.	1.13	3.15 a.m.	4.03 a.m.	.35	.13	.16	.20	.23	.26	.39	.56	.62	.73	.76				
Hannibal, Mo	9			0.39														.38			
Harrisburg, Pa	28			0.86														.41			
Hartford, Conn	20			0.40														.33			
Hatteras, N. C	19			1.57														.47			
Havre, Mont	5			0.98														.39			
Helena, Mont	24	5.22 p.m.	7.40 p.m.	0.78	5.26 p.m.	5.40 p.m.	.01	.27	.47	.54											
Houghton, Mich	27	9.25 a.m.	1.40 p.m.	1.60	10.51 a.m.	11.11 a.m.	.27	.06	.13	.36	.51										
Houston, Tex	17			0.34														.34			

[1] July 1.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Huron, S. Dak.	4	3.40 p. m.	6.15 p. m.	1.96	4.44 p. m.	5.58 p. m.	.03	.12	.18	.23	.41	.55	.67	.74	.84	.94	1.12	1.45	1.92		
	6-7	9.15 p. m.	D. N. a. m.	2.68	9.45 p. m.	11.01 p. m.	.05	.18	.23	.44	.65	.85	1.07	1.25	1.30	1.41	1.58	1.67	1.99		
					1.05 a. m.	11.33 a. m.	2.06	.09	.14	.21	.41	.51	.58								
Do.	7	7.40 p. m.	D. N. p. m.	1.80	8.47 p. m.	9.07 p. m.	.27	.14	.29	.51	.58										
					10.53 p. m.	11.01 p. m.	1.44	.23	.34												
Do.	13-14	D. N. p. m.	D. N. a. m.	0.82	11.38 p. m.	12.00 mid.	.21	.06	.14	.38	.57	.61									
Independence, Cal.	2			0.01														(*)			
Indianapolis, Ind.	10	2.19 p. m.	3.22 p. m.	0.76	2.24 p. m.	3.00 p. m.	.01								.75†						
Iola, Kans.	[1] 30-1	7.30 p. m.	1.15 p. m.	1.39	8.15 p. m.	8.48 p. m.	.01	.07	.16	.38	.53	.66	.81	.86							
Jacksonville, Fla.	14			0.49														.34			
Kalispell, Mont.	25			0.80														.22			
Kansas City, Mo.	21-22	8.50 p. m.	D. N. a. m.	1.62	9.57 p. m.	10.55 p. m.	.30	.08	.12	.34	.44	.50	.57	.63	.70	.73	.78	.94			
Keokuk, Iowa	13	7.20 a. m.	11.00 a. m.	1.75	7.36 a. m.	8.41 a. m.	.01	.09	.14	.27	.33	.35	.41	.45	.50	.58	.73	1.31	1.62		
Key West, Fla.	10-11			0.60														.54			
Knoxville, Tenn.	17-18	D. N. p. m.	9.55 a. m.	2.95	6.10 a. m.	7.27 a. m.	1.15	.09	.14	.18	.22	.26	.39	.45	.49	.58	.64	.80	1.18		
La Crosse, Wis.	4	1.35 a. m.	D. N. a. m.	0.61	2.28 a. m.	2.47 a. m.	.01	.23	.41	.48	.55										
	6	4.28 p. m.	5.20 p. m.	0.64	4.30 p. m.	5.00 p. m.	.01	.13	.32	.42	.43	.55	.62								
	26-27	10.52 p. m.	D. N. a. m.	2.82	11.47 p. m.	1.22 a. m.	.03	.25	.56	.87	1.09	1.15	1.21	1.26	1.30	1.36	1.49	1.80	2.33	2.79	
Lander, Wyo.	6			0.04														.03			
Lansing, Mich.	26			0.47														.44			
Lewiston, Idaho	27			0.19														.11			
Lexington, Ky.	1	4.29 p. m.	5.30 p. m.	1.07	4.32 p. m.	5.07 p. m.	.01	.09	.34	.55	.72	.88	.98	1.05							
	4	11.10 p. m.	12 mid.	0.63	11.25 p. m.	11.36 p. m.	.01	.25	.55	.60											
	5	12.45 a. m.	8.50 a. m.	2.34	1.04 a. m.	1.28 a. m.	.03	.09	.17	.52	.62	.72									
					2.23 a. m.	3.02 a. m.	.76	.18	.33	.38	.44	.55	.80	.91	.98						
Lincoln, Nebr.	5	8.20 p. m.	11.20 p. m.	3.70	8.54 p. m.	11.00 p. m.	0.06	.05	.14	.35	.65	.94	1.29	1.58	1.81	1.93	2.07				
								2.20	2.32	2.57	2.80	2.90	2.92	2.92	2.93	2.93	2.93				
								3.03	3.26	3.35	3.40	3.57	3.61								
	14	2.55 a. m.	5.35 a. m.	1.09	3.00 a. m.	3.16 a. m.	0.01	.42	.72	.82	.84										
Little Rock, Ark.	15			0.01														.01			
Los Angeles, Cal.	7			0.09														.02			
Louisville, Ky.	5	2.05 a. m.	7.35 a. m.	1.38	3.15 a. m.	3.32 a. m.	.39	.21	.40	.48	.52										
Ludington, Mich.	3-4	3.15 p. m.	10.40 a. m.	2.76	3.28 p. m.	3.44 p. m.	.02	.14	.31	.45	.50										
	6-7	10.02 p. m.	D. N. a. m.	2.22	10.35 p. m.	11.05 p. m.	.06	.25	.38	.55	.68	.88	1.21								
Lynchburg, Va.	26	9.35 p. m.	11.20 p. m.	1.50	9.43 p. m.	10.13 p. m.	.01	.19†	.48†	.70†	.97†	1.21†	1.39†								
Macon, Ga.	18			1.37														.63			
Madison, Wis.	19			0.49														.39			
Marquette, Mich.	27			2.55														.63			
Memphis, Tenn.	17			0.12														.12			
Meridian, Miss.	18			0.24														.24			
Miami, Fla.	11	8.07 a. m.	9.30 a. m.	1.10	8.17 a. m.	8.47 a. m.	.02	.07	.14	.32	.52	.83	.98								
Milwaukee, Wis.	22	2.35 p. m.	4.50 p. m.	1.23	3.35 p. m.	4.03 p. m.	.05	.14	.27	.54	.76	1.09	1.17								
Minneapolis, Minn.	3	1.12 a. m.	6.40 a. m.	1.48	2.26 a. m.	3.46 a. m.	.15	.06	.15	.19	.21	.34	.38	.40	.50	.64	.80	.94	1.16		
	26	7.30 p. m.	11.30 p. m.	1.60	9.04 p. m.	9.31 p. m.	.21	.07	.15	.67	1.14	1.31	1.35								
Mobile, Ala.	14	5.46 p. m.	6.40 p. m.	0.63	5.55 p. m.	6.19 p. m.	0.02	.14	.25	.35	.47	.56									
	15	2.54 p. m.	4.00 p. m.	1.05	3.01 p. m.	3.23 p. m.	0.04	.24	.51	.83	.95	1.01									
	17	4.58 p. m.	7.20 p. m.	1.77	5.55 p. m.	6.50 p. m.	0.01	.13	.22	.23	.27	.30	.32	.33	.50	.62	.70	.76			
Modena, Utah	29			0.32														.22			
Montgomery, Ala.	17	11.21 a. m.	12.10 p. m.	0.57	11.30 a. m.	11.46 a. m.	.01	.19	.36	.51	.54										
Moorhead, Minn.	8	2.55 p. m.	10.00 p. m.	2.90	3.44 p. m.	4.33 p. m.	.11	.15	.19	.48	.73	.85	1.05	1.33	1.59	1.77	1.87				
	26	3.15 p. m.	9.05 p. m.	1.82	7.30 p. m.	8.50 p. m.	.27	.09	.13	.19	.30	.42	.61	.76	.84	.90	1.00	1.28	1.51		
Mount Tamalpais, Cal.	6			0.43														.05			
Mount Weather, Va.	27	1.07 p. m.	2.15 p. m.	0.90	1.11 p. m.	1.29 p. m.	.01	.23	.47	.78	.86										
Nantucket, Mass.	4-5			1.18														.45			
Nashville, Tenn.	15	2.13 p. m.	4.00 p. m.	1.71	2.15 p. m.[2]	2.45 p. m.[2]	T.[3]						[3] 1.71								
New Haven, Conn.	4			0.88														.23			
New Orleans, La.	6	2.55 p. m.	3.35 p. m.	0.56	2.58 p. m.	3.17 p. m.	.01	.15	.35	.53	.55										
New York, N. Y.	24			0.26														.26			
Norfolk, Va.	12	4.30 p. m.	7.10 p. m.	0.69	5.12 p. m.	5.23 p. m.	.07	.35	.58	.61											
Northfield, Vt.	19			0.56														.42			
North Head, Wash.	23			0.87														.32			
North Platte, Nebr.	12	8.02 p. m.	10.15 p. m.	1.17	8.05 p. m.	8.30 p. m.	.01	.32	.65	.91	1.02	1.07									
	20-21	11.50 p. m.	D. N. a. m.	0.65	11.57 p. m.	12.18 a. m.	.01	.24	.39	.47	.52										
Oklahoma, Okla.	1-3			0.01														.01			
Omaha, Nebr.	5-6	9.25 p. m.	12.15 a. m.	1.08	10.16 p. m.	10.47 p. m.	.02	.11	.27	.39	.51	.66	.80	.81							
	13	12.35 a. m.	6.20 a. m.	1.44	2.34 a. m.	3.18 a. m.	.32	.10	.22	.27	.40	.61	.77	.87	.91	.98					
	14	2.35 a. m.	6.15 a. m.	1.03	2.44 a. m.	3.08 a. m.	.03	.13	.35	.47	.57	.63									
Oswego, N. Y.	7			0.35														.34			
Palestine, Tex.	18-23			T.														T.			
Parkersburg, W. Va.	4			0.70														.41			
Pensacola, Fla.	16	11.15 a. m.	12.15 p. m.	1.05	11.29 a. m.	12.04 p. m.	.01	.10	.15	.31	.60	.78	.99	1.03							
	17	6.30 p. m.	8.05 p. m.	0.68	7.23 p. m.	7.51 p. m.	.01	.07	.14	.28	.54	.64	.67								
	18	10.40 a. m.	12.40 p. m.	0.92	12.14 p. m.	12.25 p. m.	.30	.24	.60	.62											
Peoria, Ill.	27	3.20 a. m.	4.00 a. m.	0.56	3.29 a. m.	3.55 a. m.	.01	.10	.22	.24	.40	.54	.55								
Philadelphia, Pa.	27	3.18 p. m.	4.20 p. m.	1.61	3.21 p. m.	4.15 p. m.	.01	.15	.37	.58	.79	.93	1.02	1.03	1.05	1.27	1.47	1.60			
		5.40 p. m.	8.10 p. m.	0.56	7.18 p. m.	7.43 p. m.	.05	.10	.20	.32	.42	.50									
Phoenix, Ariz.	1-2			0.05														.02			
Pierre, S. Dak.	4	8.03 p. m.	8.45 p. m.	0.86	8.07 p. m.	8.29 p. m.	.03	.10	.25	.46	.74	.81									
Pittsburgh, Pa.	27-28	9.55 p. m.	2.40 a. m.	1.72	10.09 p. m.	10.39 p. m.	.01	.09	.23	.26	.38	.52	.61								
					1.58 a. m.	2.18 a. m.	.94	.19	.63	.71	.76										
Pocatello, Idaho	12			0.29														.29			
Point Reyes Light, Cal.	6			0.20														.06			
Port Huron, Mich.	3			0.59														.17			
Portland, Me.	29			0.54														.45			
Portland, Oreg.	5-6			0.80														.07			
Providence, R. I.	20			0.13														.13			
Pueblo, Colo.	11	6.02 p. m.	6.38 p. m.	0.54	6.02 p. m.	6.27 p. m.	.00	.13	.16	.19	.43	.51									
Raleigh, N. C.	21			0.53														.48			
Rapid City, S. Dak.	16	12.40 p. m.	2.20 p. m.	1.28	1.20 p. m.	1.51 p. m.	.04	.33	.63	.81	.89	1.04	1.20	1.22							
Reading, Pa.	24			0.59														.56			
Red Cliff, Cal.	24			0.83														.37			
Reno, Nev.	19			0.26														.07			
Richmond, Va.	25	8.46 p. m.	11.45 p. m.	1.50	9.10 p. m.	9.52 p. m.	.02	.08	.19	.45	.76	.98	1.14	1.24	1.31	1.35					
Rochester, N. Y.	19			0.64														.40			
Roseburg, Oreg.	24	3.10 p. m.	3.50 p. m.	0.45	3.26 p. m.	3.41 p. m.	.02	.07	.32	.43											
Roswell, N. Mex.	2			0.87														.48			
Sacramento, Cal.	24			0.23														.11			
Saginaw, Mich.	26	11.18 a. m.	1.12 p. m.	0.70	11.35 a. m.	11.56 a. m.	.06	.16	.28	.40	.49	.53									

[1] July 1. [2] About; eye observation; top of gage blown off. [3] Stick measurement.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
St. Joseph, Mo	30	2.28 p. m.	9.30 p. m.	2.44	4.58 p. m.	5.57 p. m.	.51	.09	.28	.39	.49	.58	.62	.66	.73	.91	1.35	1.52			
St. Louis, Mo	12			0.07														.05			
St. Paul, Minn	3	1.15 a. m.	6.15 a. m.	1.54	3.16 a. m.	4.06 a. m.	.50	.07	.19	.21	.26	.31	.36	.53	.62	.76	.85				
	5	10.00 p. m.	11.30 p. m.	0.73	10.03 p. m.	10.25 p. m.	.01	.20	.24	.30	.45	.51									
Salt Lake City, Utah	3-4			0.81														.20			
San Antonio, Tex	1			0.01														.01			
San Diego, Cal	1			T.														T.			
Sand Key, Fla	22			0.10														.10			
Sandusky, Ohio	21	5.58 p. m.	6.35 p. m.	0.57	6.18 p. m.	6.30 p. m.	.01	.34	.53	.56											
San Francisco, Cal	23			0.14														.03			
San Jose, Cal	19			0.12														.06			
San Luis Obispo, Cal	6-7			0.22														(*)			
Santa Fe, N. Mex	16	7.13 p. m.	8.50 p. m.	1.00	7.33 p. m.	8.05 p. m.	.05	.07	.17	.26	.54	.80	.85	.89							
Sault Ste. Marie, Mich	27			1.00														.28			
Savannah, Ga	18			1.05														.63			
Scranton, Pa	27			0.55														.44			
Seattle, Wash	6			0.21														.21			
Sheridan, Wyo	26			0.76														.65			
Shreveport, La	13	3.15 p. m.	3.40 p. m.	1.02	3.17 p. m.	3.37 p. m.	.01	.32	.53	.78	1.01										
	17	10.10 a. m.	10.50 a. m.	0.59	10.14 a. m.	10.28 a. m.	.01	.28	.39	.53											
Sioux City, Iowa	10	8.27 p. m.	D.N.a. m.	1.20	8.30 p. m.	8.43 p. m.	.01	.24	.52	.62											
	17	2.56 p. m.	6.28 p. m.	0.86	5.46 p. m.	6.06 p. m.	.32	.07	.28	.46	.51										
Spokane, Wash	2			0.16														.16			
Springfield, Ill	13	12.24 p. m.	1.35 p. m.	0.71	12.26 p. m.	12.35 p. m.	.01	.47	.53												
Springfield, Mo	15-16			0.95														(†)			
Syracuse, N. Y	28	1.17 p. m.	2.50 p. m.	1.36	1.35 p. m.	2.18 p. m.	.03	.12	.34	.49	.66	.80	.97	1.07	1.16	1.24					
Tacoma, Wash	24			0.60														.27			
Tampa, Fla	30			1.12														.78			
Tatoosh Island, Wash	24			0.51														.16			
Taylor, Tex	1			0.09														.09			
Terre Haute, Ind	13	2.15 p. m.	8.10 p. m.	0.61	2.42 p. m.	2.52 p. m.	.05	.14	.32												
Thomasville, Ga	17	5.08 p. m.	7.20 p. m.	1.04	5.21 p. m.	5.59 p. m.	.02	.11	.41	.66	.74	.78	.86	.91	.94						
Toledo, Ohio	4	1.29 p. m.	3.35 p. m.	1.00	1.31 p. m.	1.46 p. m.	.01	.44	.74	.91											
Tonopah, Nev	7			0.22														.14			
Topeka, Kans	9	7.41 p. m.	10.00 p. m.	1.11	8.40 p. m.	8.56 p. m.	.25	.23	.39	.46	.50										
	15	2.25 a. m.	7.48 a. m.	1.27	2.36 a. m.	3.04 a. m.	.03	.10	.28	.48	.62	.76	.82								
	21	7.46 p. m.	11.20 p. m.	2.16	8.02 p. m.	8.50 p. m.	.01	.09	.23	.35	.69	.99	1.21	1.24	1.35	1.47	1.52				
Valentine, Nebr	12	4.25 p. m.	7.20 p. m.	0.72	5.39 p. m.	5.59 p. m.	.16	.08	.26	.39	.47										
	29-30	10.00 p. m.	D. N. a. m.	0.75	12.21 a. m.	12.35 a. m.	.16	.18	.36	.48											
Vicksburg, Miss	10	2.33 p. m.	3.20 p. m.	1.02	2.36 p. m.	3.09 p. m.	.01	.08	.12	.30	.51	.80	.93	1.00							
Walla Walla, Wash	13			0.33														.18			
Washington, D. C	25	12.35 a. m.	3.20 a. m.	0.89	12.38 a. m.	12.53 a. m.	.01	.34	.74	.85											
	28	4.34 p. m.	10.37 p. m.	2.41	5.07 p. m.	6.11 p. m.	.04	.07	.18	.32	.62	.86	1.00	1.12	1.23	1.38	1.48	1.57	1.64		
Wichita, Kans	1			0.99														.60			
Williston, N. Dak	3	1.55 p. m.	4.45 p. m.	1.50	2.08 p. m.	3.02 p. m.	.02	.11	.25	.58	.82	1.00	1.09	1.12	1.17	1.21	1.33	1.44			
Wilmington, N. C	18-19			0.46														.24			
Winnemucca, Nev	19-20			1.56														.52			
Wytheville, Va	5-6			0.37														.22			
Yankton, S. Dak	5-6	6.20 p. m.	12.15 a. m.	1.67	8.48 p. m.	9.17 p. m.	.50	.10	.22	.36	.49	.61	.69								
	10	4.45 p. m.	5.40 p. m.	0.73	5.04 p. m.	5.23 p. m.	.03	.08	.29	.58	.69										
Yellowstone Park, Wyo	11-12			0.64														.28			

* Self-register not working. † Record partly estimated. ‡ No precipitation occured during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, June 1914.*

Stations.	Pressure in inches. Station reduced to mean of 24 hours.	Pressure in inches. Sea level reduced to mean of 24 hours.	Pressure in inches. Departure from normal.	Temperature (°F.). Mean max.+ mean min. ÷2.	Temperature (°F.). Departure from normal.	Temperature (°F.). Mean maximum.	Temperature (°F.). Mean minimum.	Temperature (°F.). Highest.	Temperature (°F.). Lowest.	Precipitation in inches. Total.	Precipitation in inches. Departure from normal.	Precipitation in inches. Total snowfall.
St. Johns, N. F.	29.72	29.86	−.05	51.4	−0.2	60.2	42.6	75	32	2.49	−1.11	
Sydney, C. B. I.	29.86	29.90	−.05	52.4	−3.0	62.7	42.2	78	34	2.12	−1.11	
Halifax, N. S.	29.81	29.92	−.03	55.9	−1.8	67.8	43.9	87	32	5.36	+1.60	
Yarmouth, N. S.	29.86	29.93	−.02	53.6	−1.4	61.1	46.2	69	35	3.92	+1.16	
Charlottetown, P. E. I.	29.83	29.87	−.05	55.0	−2.4	64.0	46.1	79	37	5.32	+2.65	
Chatham, N. B.	29.84	29.86	−.03	57.0	−3.0	68.2	45.7	88	30	5.39	+1.93	2.0
Father Point, Que	29.82	29.84	−.03	51.6	−1.4	59.8	43.4	76	32	2.16	− .82	0.1
Quebec, Que.	29.57	29.89	−.03	58.2	−3.0	68.0	48.0	86	32	2.99	− .66	
Montreal, Que.	29.70	29.90	−.04	62.1	−2.8	71.1	53.1	88	40	2.90	− .63	
Stonecliffe, Ont.	29.35	29.95	+.01	60.0	−1.6	73.4	46.5	96	30	3.25	+ .09	
Ottawa, Ont.	29.68	30.00	+.06	62.2	−3.1	72.0	52.4	85	39	2.92	.00	
Kingston, Ont.	29.65	29.96	−.01	63.8	+0.4	69.7	57.9	85	45	2.91	+ .48	
Toronto, Ont.	29.58	29.95	−.02	64.4	+1.0	74.8	54.0	91	38	2.17	− .63	
White River, Ont.	28.66	29.96	+.02	54.3	−4.4	71.0	37.6	91	22	0.70	−1.52	
Port Stanley, Ont.	29.37	30.01	+.04	62.1	-1.7	71.8	52.4	88	36	2.27	− .46	
Southampton, Ont.	29.31			59.5	− 9.9	69.5	49.5	89	33	2.29	− .06	
Parry Sound, Ont.	29.30	29.98	+.02	60.4	−1.3	72.7	48.1	93	35	1.91	− .51	
Port Arthur, Ont.	29.29	30.00	+.06	58.0	+1.6	70.6	45.5	85	36	1.30	−1.43	
Winnipeg, Man.	29.11	29.93	+.04	63.2	+1.0	75.3	51.0	89	35	1.46	−1.83	
Minnedosa, Man.	28.14	29.93	+.04	59.4	−0.2	71.9	47.0	89	31	1.39	−1.61	
Qu'Appelle, Sask.	27.65	29.87	.00	58.9	+1.0	70.7	47.1	90	38	3.34	− .08	
Medicine Hat, Alberta	27.58	29.82	−.03	64.0	+2.0	78.7	49.4	96	41	2.00	− .76	
Swift Current, Sask.	27.30	29.82	−.05	60.0	0.0	72.9	47.2	91	37	2.31	− .36	
Calgary, Alberta	26.35	29.82	−.02	57.7	+1.7	71.4	44.1	89	31	2.64	+ .19	
Banff, Alberta	25.35	29.88	+.04	52.5	+1.0	64.7	40.3	79	33	1.81	−1.52	
Edmonton, Alberta	27.60	29.86	+.02	57.5	+0.6	68.1	46.9	84	39	8.53	+5.67	T.
Battleford, Sask.	28.15	29.86	.00	61.4	+1.9	73.1	49.6	88	40	2.47	− .84	
Kamloops, B. C.	28.68	28.88	+.01	63.9	+0.1	76.8	51.1	92	41	0.54	− .88	
Victoria, B. C.	29.78	29.98	−.03	55.9	−0.4	62.7	49.0	78	42	1.67	+ .47	
Barkerville, B. C.	25.64	29.92	+.05	50.4	−0.3	61.9	39.0	75	30	4.39	+ .91	
Hamilton, Bermuda	30.01	30.17	+.05	73.2	−1.8	78.3	68.1	81	61	2.08	−3.87	

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Chart I. Hydrographs of Several Principal Rivers, June, 1914.

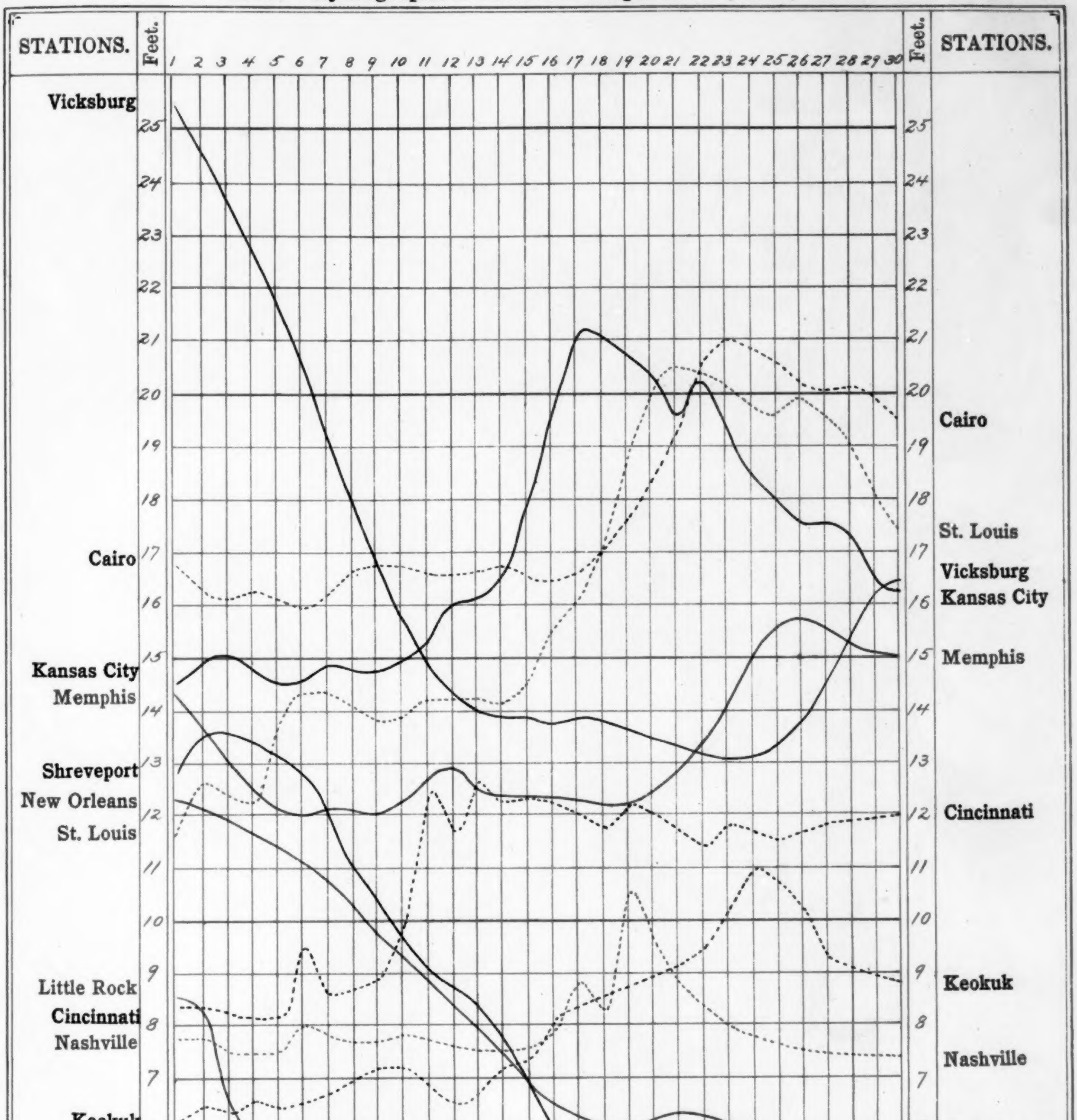

Chart II. Tracks of Centers of High Areas, June, 1914.

Chart III. Tracks of Centers of Low Areas, June, 1914.

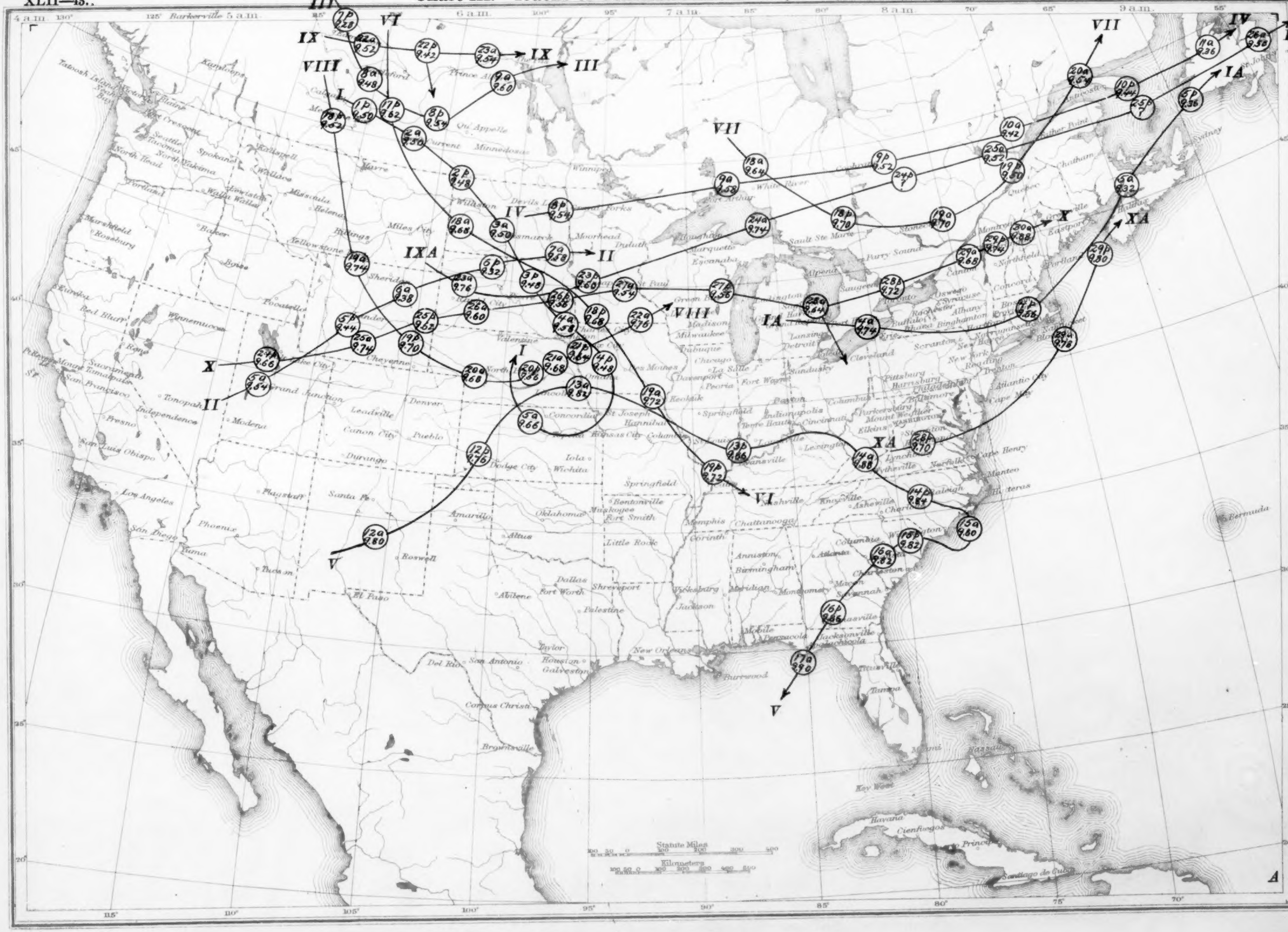

Chart IV. Departure of the Mean Temperature from the Normal, June, 1914.

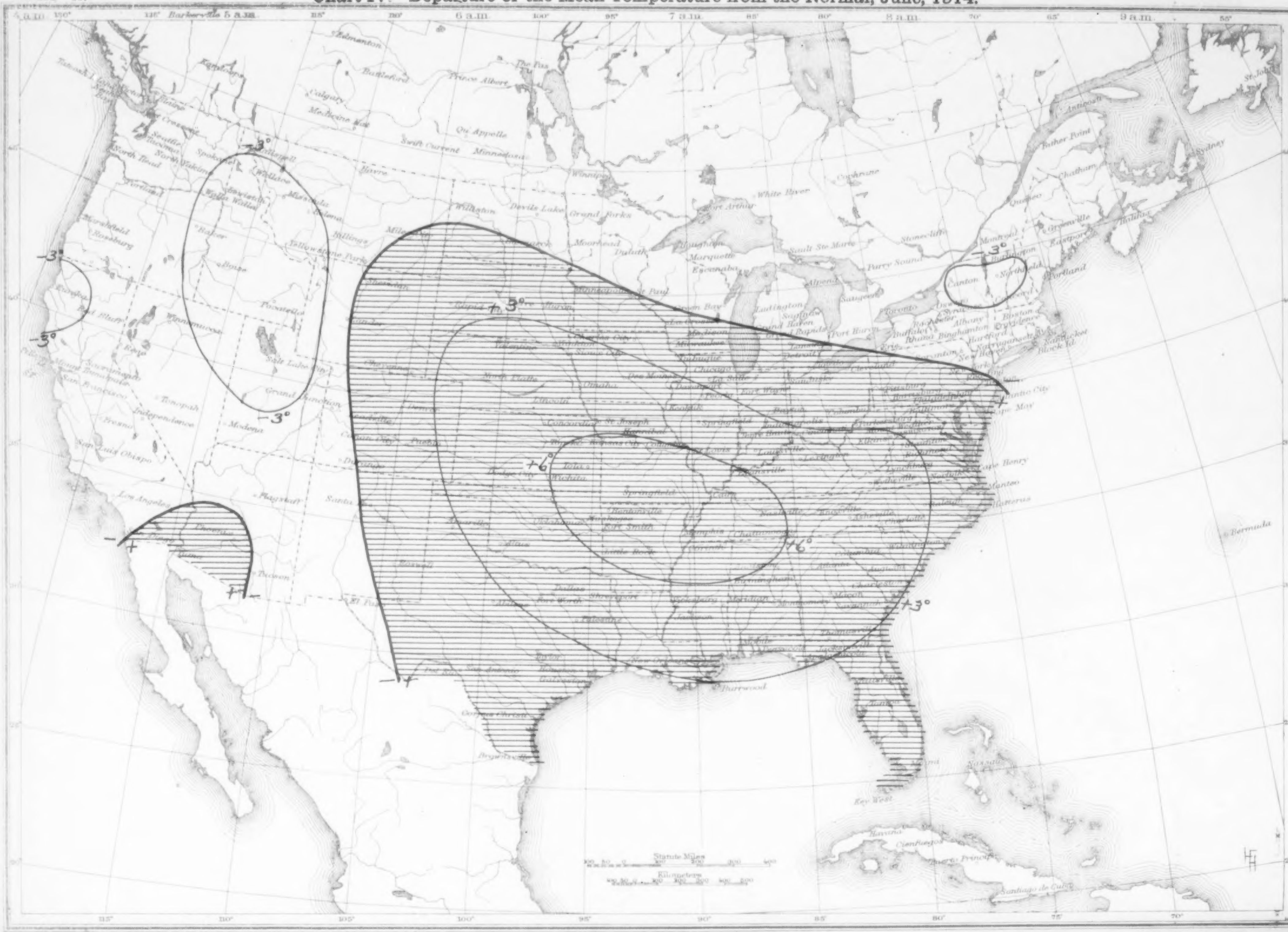

Chart V. Total Precipitation, inches, June, 1914.

Chart V. Total Precipitation, inches, June, 1914.

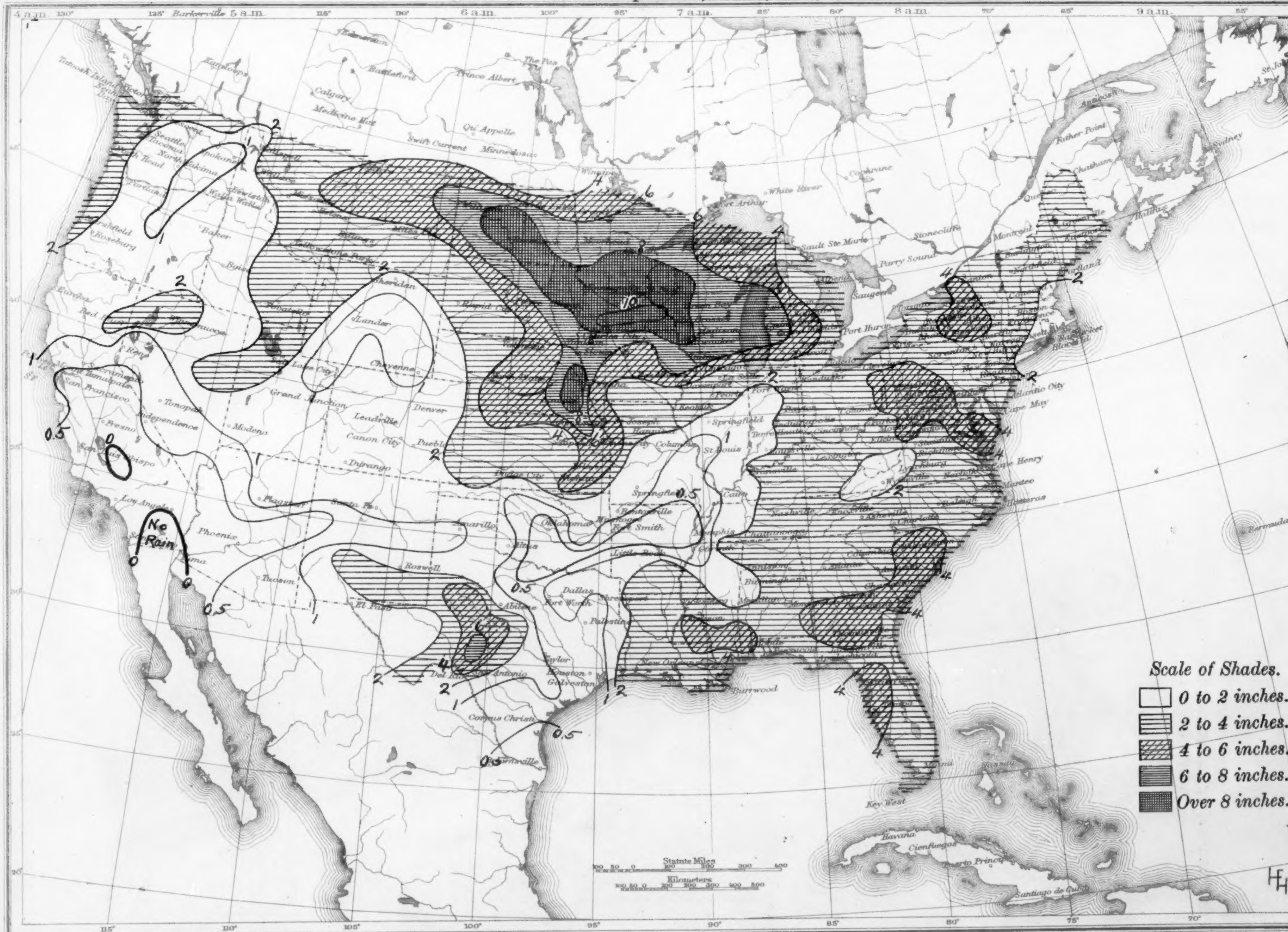

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, June, 1914.

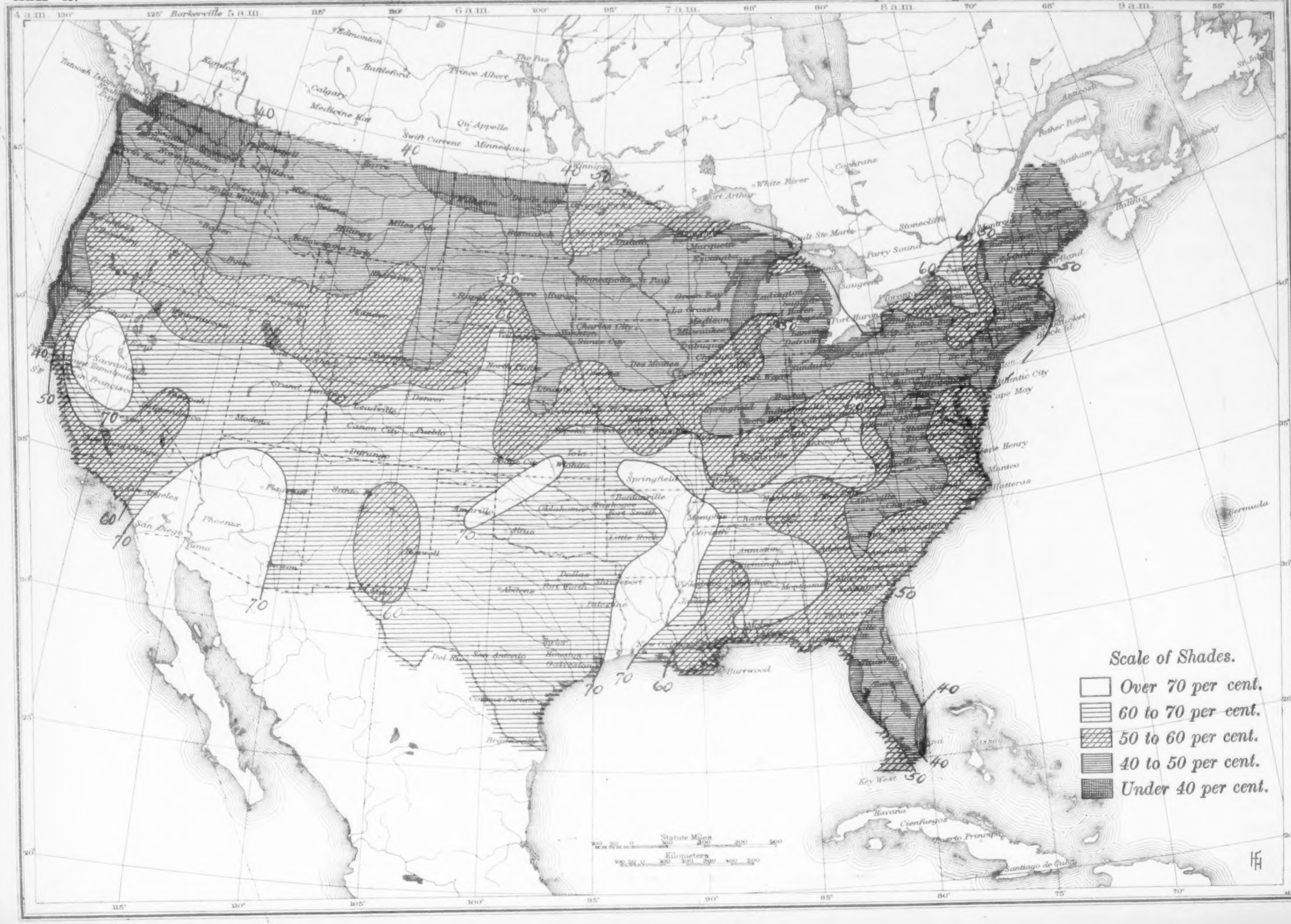

Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, June, 1914.